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Sediment transport and coastal evolution at Thuan An Inlet, Vietnam

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Abstract

The Tam Giang-Cau Hai lagoon is located outside of Hue in central Vietnam. Southeast of Thuan An inlet, one of the two inlets of the lagoon, a groin was constructed in 2008 as a measure to reduce the sediment transport to prevent the inlet from closing. This groin has caused erosion of the eastern sand spit of the inlet and accretion of sediment on the coastline south east of the groin. The objectives of this study was to make a model of the sediment transport on the southeast side of the groin to be able to analyse how different measures to reduce the erosion of the inlet would affect the sediment transport past the groin.

The field measurements and parts of the data collection took place in Vietnam during nine weeks in the beginning of 2013. The position of the coastline at Thuan An inlet was measured and the rest of the data, such as e.g. wave data, bathymetry data, previously measured coastlines and sediment transport was obtained from Institute of Mechanics in Hanoi. Other data used in this thesis was also obtained from The University of Agriculture and Forestry in Hue and from The Oceanographic Institute in Nha Trang. The study area has a tropical monsoon climate with two monsoon season per year – the southeast monsoon and the northwest monsoon. The micro tidal climate in the area is fully semi-diurnal and gives that the main sediment transport is wave induced.

The modelling software GENESIS was used to model the sediment transport past the groin. The model was calibrated and validated using measured data and then the sediment transport on the southeast side of the groin was modelled during the years 2013 to 2017. First, the case where no measures were taken was modelled, to see what will happen if no changes of the groin were made. After that, three different measures to decrease the accretion of sediment on the southeast side of the groin (i.e. increase the sediment transport past the groin in order to reduce the erosion of the Thuan An inlet) were modelled and analyzed. These three measures were making the groin shorter, increasing the permeability of the groin and dredging sand from southeast side of the groin.

The result of the model and the different measures to reduce erosion were discussed. The conclusion was that interventions to reduce the erosion are needed to protect the lagoon and the people living around it and making their livelihood from it. Many people work with e.g. fishery, aquaculture and agriculture and these occupations could be severely affected of the results of continuous erosion, such as changed water environment in the lagoon and flooding.

Keywords: Thuan An, Hoa Duan, Tam Giang-Cau Hai lagoon system, lagoon, inlet, groin, longshore sediment transport, Thua Thien-Hue province, GENESIS, Huong River

Sammanfattning

Tam Giang-Cau Hai-lagunen är belägen utanför Hue i centrala Vietnam. Sydöst om Thuan An-inloppet - ett av de två inloppen till lagunen - konstruerades år 2008 en hövd som en åtgärd för att minska sedimenttransporten till inloppet. Detta för att förhindra att inloppet skulle stängas. Hövden har orsakat erosion av den östra sidan av Thuan An-inloppet och ansamling av sediment vid stranden på den sydöstra sidan av hövden. Målsättningen med denna studie var att skapa en modell över sedimenttransporten på den sydöstra sidan av hövden för att kunna analysera olika åtgärder för att minska erosionen vid inloppet och hur de påverkar sedimenttransporten förbi hövden.

Fältmätningarna och delar av datainsamlingen utfördes i Vietnam under nio veckor i början av 2013. Kustlinjens position vid Thuan An-inloppet mättes och resterande data, t.ex. vågdata, batymetri, tidigare uppmätta kustlinjer och datan över sedimenttransport erhölls från Institute of Mechanics i Hanoi. Övrig data som har använts i denna uppsats har även fåtts från University of Agriculture and Forestry i Hue och Oceanographic Institute i Nha Trang. I det studerade området råder tropiskt monsunklimat med två monsunperioder per år – den sydöstra och den nordvästra monsunen. Tidvattenklimatet är fullständigt diurnalt, vilket ger att majoriteten av sedimenttransporten orsakas av vågor.

För att modellera sedimenttransporten förbi hövden användes modelleringsprogrammet GENESIS. Modellen kalibrerades och validerades med hjälp av uppmätta data och sedan modellerades sedimenttransporten på sydöstra sidan av hövden för åren 2013-2017. Först modellerades fallet då inga åtgärder vidtas, för att se vad som händer om inga förändringar av hövden sker. Sedan modellerades och analyserades tre olika åtgärder för att minska ansamlingen av sediment på den sydöstra sidan av hövden (d.v.s. för att öka mängden sediment som transporteras förbi hövden och på så sätt minska erosionen vid Thuan An-inloppet). De tre studerade åtgärderna var att korta av hövden, att öka dess permeabilitet och att utföra bortschaktning av sediment från den sydöstra sidan av hövden.

Modellresultaten vid användning av de olika åtgärderna diskuterades. Slutsatsen var att åtgärder för att minska erosionen är nödvändiga för att skydda lagunen och de som lever av den och bor i området. Många invånare i provinsen arbetar med t.ex. fiske, vattenbruk och jordbruk och dessa sysselsättningar kan komma att påverkas påtagligt av resultaten av fortsatt erosion, såsom en ändrad vattenmiljö i lagunen eller översvämningar.

Nyckelord: Thuan An, Hoa Duan, Tam Giang-Cau Hai, lagun, inlopp, hövd, sedimenttransport, Thua Thien-Hue-provinsen, GENESIS, Huong River

Preface

Both of us had for a long time been interested in doing our master thesis abroad and in the fall of 2011 we went to a seminar about the SIDA-financed scholarship program Minor Field Studies (MFS). During the seminar different people whom had carried out a MFS held a presentation regarding to which country they had went, what project they worked with and their overall experiences.

The scholarship program has the aim to prepare students to operate in a global context and to give universities the possibilities to establish and strengthen international contacts. This was something that seemed very appealing to us, since both of us are doing are master in Water Resources Management and are interested in working with the global problems regarding this topic.

Professor Magnus Larson at the division of Water Resources Engineering at Lund University told us about this project in Vietnam that he has been involved in for some years, and it was very interesting to us.

In the middle of January 2013 we went to Vietnam for 8 weeks and made a field study, associated with people working at different universities throughout the country and got to know the culture of Vietnam. A personal objective with the trip was to gain experience of fieldwork, research and daily life in Vietnam, a country with different culture, religion and habits than in Sweden.

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The MFS Scholarship Programme offers Swedish university students an opportunity to carry out two months' field work in a developing country resulting in a graduation thesis work, a Master's dissertation or a similar in-depth study. These studies are primarily conducted within subject areas that are important from an international development perspective and in a country supported by Swedish international development assistance.

The main purpose of the MFS Programme is to enhance Swedish university students' knowledge and understanding of developing countries and their problems. An MFS should provide the student with initial experience of conditions in such a country. A further purpose is to widen the human resource base for recruitment into international co-operation. Further information can be reached at the following internet address: http://www.tg.lth.se/mfs

The responsibility for the accuracy of the information presented in this MFS report rests entirely with the authors and their supervisors.

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1. Introduction

This chapter introduces a general background of Vietnam and the specific study area at Thuan An inlet. The objectives and limitations of this study and the applied procedure are also presented.

1.1. Background

Vietnam is located in the southeast part of Asia and has most of its coast adjacent to the South China Sea. The Thuan An inlet is one of two inlets to the Tam Giang-Cau Hai lagoon system, located in the middle of the country, see Figure 1:1. Huong River spills out in the lagoon and Hue City is found upstream of the river mouth, approximately 10 km inland, which was the capital of Vietnam 1802-1945 (Inman & Harris 1966).

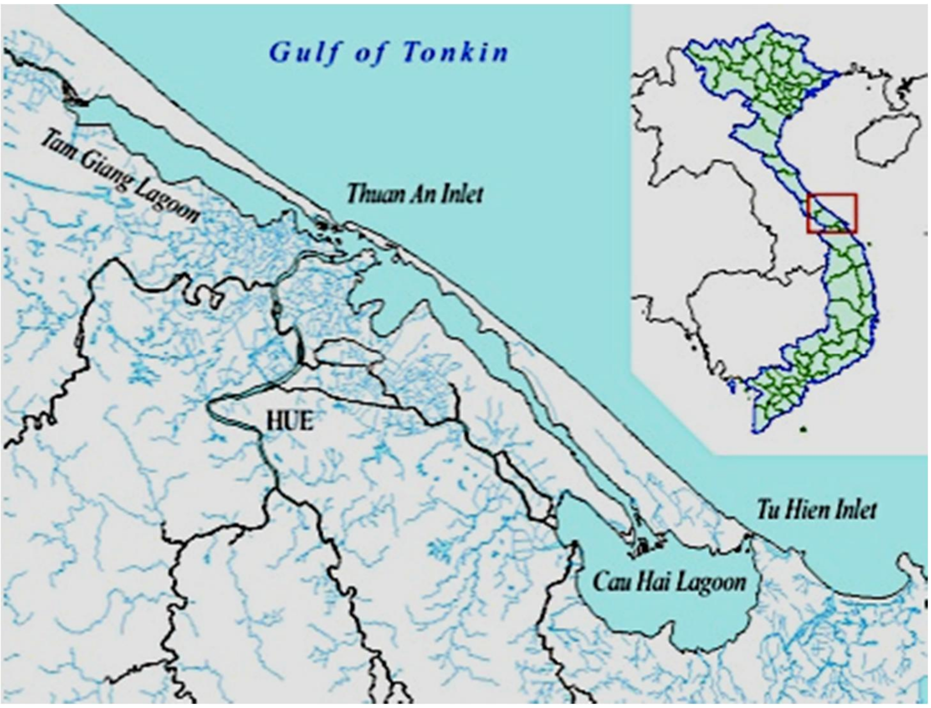

Figure 1:1 The location of the Tam Giang-Cau Hai lagoon system in Vietnam (Lam 2009)

A lagoon is a water body that is separated from the ocean by a barrier, usually orientated parallel to the shore. The lagoon is usually shallow and connected to the ocean by one or more inlets (Kjerve 1994). Lagoons were formed when the sea level rose during the Holocene; many of the headlands along the Vietnamese coast were islands during the Holocene that got connected to the coast by littoral deposition (Inman & Harris 1966).

The current position of the Thuan An inlet opened up in 1897 by a storm, and the same storm closed the old inlet which was located 4 kilometres southeast of the present entrance. In the early 1930's a breakwater to minimize saltwater intrusion was constructed to conserve the fresh water of the lagoon system for irrigation (Inman & Harris 1966). The breakwater broke down during heavy flooding in 1953 and was removed by the US Army in 1965. The same year the US Army built a steel jetty south of the inlet, to prevent siltation and to create a harbour for army boats, which lasted for ten years. In 1997 another attempt to stabilize the beach and reduce the erosion was made when building five groins some kilometres south of Thuan An inlet. One year after completion the groins were damaged and stopped working (Tung 2001).

The beach south of Thuan An inlet is mainly eroded by the longshore sediment transport that transports the sediment to the northwest. A portion of the sediment settles in the inlet, which has led to that the inlet is getting narrower and shallower because of all the accreted sand. The erosion of the beach mainly takes place during the northeast monsoon and during the southwest monsoon the beach accretes. The net transport of the sediment erodes the beach severely and leads to problems for the people living there. The lagoon is of high economic value for the people in the province, the lagoon system is about 30 % of the total area of the province but 80 % of the population lives there and makes a living from e.g. fishing and aquaculture (Hung 2012). Tung (2001) suggests as a solution to prevent the continuing erosion and sedimentation by the construction of a groin field south of the inlet. Inman & Harris (1966) suggested the building of a breakwater to stabilize the channel entrance.

Thus, in 2008 a groin was built southeast of the inlet, to prevent sedimentation in the inlet. However, this groin has caused severe erosion of the sand spit reaching into the inlet from the east (the barrier island located between the lagoon and the ocean) and sediment is adding up on the southeast side of the groin (Dien et al. 2011). The erosion is progressing towards the downdrift side of the groin, potentially causing problems for the structure, as well as resulting in significant loss of land.

1.2. Problem identification

One of today's largest problems in the region of the Tam Giang-Cau Hai lagoon system and around Thuan An inlet is the erosion of the barrier islands southeast of the inlet and the infilling of the inlet. The erosion of the beach southeast of Thuan An inlet results in a movement of the inlet that cause problems for navigation, fishery, flooding discharge, and the ecological system inside the lagoon. In the area different fishing industries are of significant economic value, so the marine environment has a main role in the provinces' economic growth. The erosion of the shoreline also causes damage to the infrastructure and the beaches, which for example affects the tourism (Tung 2001).

If the sand spit on the east side of the inlet will breach it will change the ecology of the lagoon through an alteration of the balance between saltwater and freshwater.

The species living in the lagoon today cannot survive in a changed ecosystem and it will have a great impact on the fishing and aquaculture. A total siltation of the inlet is also impending and will cause problems for fishing activities, navigation of cargo and passenger ships heading for Thuan An harbour. Last but not least coastal protection is for the people living in the area, to protect their homes and livelihood (Tung 2001). The combination of a shallow lagoon with the migration as well as the siltation of the inlet decrease the evacuation capacity of a flood and increase the chance of an overflow. This can have severe consequences such as loss of human life, properties, livestock, crops, infrastructure and environmental pollution (Lam 2002). The sand barrier island protects the coastal plains from a direct strike from a typhoon or extreme weather, but it also block flood waters coming from the rivers to flow out into the sea (Tung 2011).

The groin was built in 2008 on the southeast side of Thuan An inlet and five years after the construction of the groin the main problem is that the sand spit on the east bank of the inlet is eroding due to lack of sediment transport from the southeast, because of the groin.

1.3. Objectives

The main objective was to investigate the sediment transport pattern and resulting coastal evolution at Thuan An inlet near Hue City in Vietnam. In 2008 a groin was built just south of the inlet, which altered the pattern of sediment transport in the area. The shoreline southeast of the groin was eroding before the groin was built and after the construction of the groin the beach started to accrete. The severe siltation of Thuan An inlet ended when the groin was built and today the inlet lack accretion of sediment, which is leading to erosion of the eastern banks of the inlet. The main objective included modelling of the sediment transport on the southeast side of the groin and discussing the effect of different measures to reduce the erosion. Also the perspective of how the erosion could affect the socio-economic situation was discussed.

1.4. Limitations

The modelling only focused on the groin and the shoreline southeast of the groin, the inlet at Thuan An was not included in the model. This limitation was set due to that the hydromechanics of the inlet (with the alternating flow from the inland rivers and the tide from the ocean) are complicated to re-create and it would have taken to long time to build a model. The chosen modelling program (GENESIS) models in one dimension and this is not sufficient to build a model of the whole study area, including the inlet, the river flow and the adjacent beaches.

The morphodynamic of the inlet and factors that affect its' stability has a big importance regarding the design of the groin and the stability of the study area, so the mechanisms regarding the stability of the inlet was still included in the thesis.

1.5. Procedure

First, a literature study was carried out to collect relevant information and to get a good understanding of the processes and problems of Thuan An inlet and surrounding coastal areas. Previous studies of the inlet and already collected data were reviewed and relevant information was compiled and analysed. Focus was on hydrodynamics, sediment transport, and coastal evolution at the inlet. Also general literature concerning nearshore waves, currents, inlets processes and socio-economic studies of the lagoon were consulted. Already measured data on shorelines, nearshore hydrodynamics, wave data and information about the inlet and the groin was analysed and relevant data compiled.

The field measurements were carried out during January 2013 and took place at Thuan An inlet, near Hue in Vietnam. The field measurements were carried out to collect additional data, focusing on the shoreline located north and south of the inlet. To record the location of the shoreline a GPS was used and the field measurements was carried out along with three researchers from Institute of Mechanics in Hanoi (IMS). Talking to the people at Hue University of Agriculture and Forestry (HUAF) and visiting some villages around the lagoon during the field measurements obtained a basic knowledge about the daily life around the lagoon. At the Oceanographic Institute in Nha Trang the hydrodynamics of the ocean and along the coastline outside Thuan An was studied.

Besides the data collected during the field measurements, previously measured data was obtained from IMS. The received data was wave characteristics from the years 1991-2012, shoreline measurements at Thuan An inlet from 2007-2012, bathymetry data and information regarding the groin. Data concerning beach profiles, sediment samples and grain-size analysis was found through earlier conducted studies and thesis. A major part of the data compilation was performed in Hanoi.

To simulate the coastal evolution around the inlet the shoreline change model GENESIS was used. After the model was calibrated and validated with available field data, different measures to lessen the impact of the groin and to reduce inlet erosion was modelled. Measured input data that was needed for the model was inter alia information about structures present, beach fill configurations, shoreline positions, beach profile shape and slope, offshore wave information and related reference depths.

2. Coastal processes

This chapter explains basic theory to give the reader necessary knowledge to understand the basics of this thesis – such as introducing information about coastal lagoons, sea level changes, longshore sediment transport, coastal inlets and coastal protection structures.

2.1. Waves

Waves are generated at open sea by the wind that blow across the ocean and transfer some of its energy to the water. The generated waves are called wind waves or oscillatory waves. The waves move towards land where their energy is distributed along the shore (SPM 1984a). Wind waves affect ships, structures and all actions in seas, which make them an important marine dynamic process. Waves approaching the shore causes coastline erosion, sea bottom changes and affect structures, ports etc. The spreading of pollutions in coastal zones is also affected by waves and wave induced currents (Hung 2012). The waves move in the direction of the wind until it reaches land. When the wave is at deep water it is only the wave shape and part of the wave energy that moves forward, the water particles stays in almost the same place, just moving in a circular pattern. The characteristics of a wave are determined by the distance the wind is allowed to blow (the fetch), the wind speed, the duration of the wind and the water depth. The wave height is the distance between the wave crest and the wave trough and the wave length L is the horizontal distance between two wave crests or wave troughs. The wave period T is the time it takes for two wave crests, one after another, to pass a specified point (SPM 1984a). See Figure 2:1 for an illustration of wave characteristics.

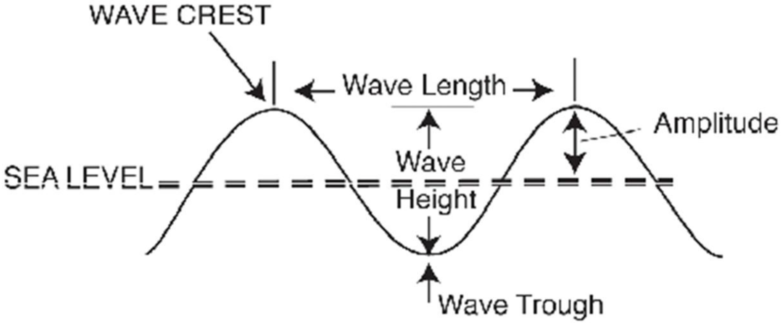

Figure 2:1 Wave characteristics (SECOORA)

In deep water the speed of an individual wave is higher than the velocity of a group of waves or a wave train in which the individual wave is part. In shallow water the velocity of a group of waves and an individual wave are equal. The wave speed is given by

$$C = \frac{L}{T}$$

The wave celerity decreases with depth and proportionally the wave length also must decrease, since the wave period is the same for shallow and deep water. When a wave travels towards shallower water the wave height will increase due to that the decrease in velocity gives an increase in energy density to maintain the energy flux and it is called shoaling. Also when a wave approaches the beach the wave crest moves at an angle to underwater bottom contours and the part of the wave in deeper water will be moving faster than the part in shallow water, which causes the wave to bend. This is called refraction and together with shoaling it determines the wave height in any water depth (SPM 1984b).

When a wave approaches a beach it will begin to break at a water depth equal to 1.3 times the wave height and the wave will break through either plunging, spilling, surging or collapsing. When breaking some of the wave energy will create turbulence in the water that also causes some sediment transport and the remaining energy is dissipated when the wave rushes up on the beach as a foaming, turbulent mass. During storms or other extreme weather the strong winds generate high, steep waves and often a raise in the water level, called a storm surge, is formed that exposes higher parts to the beach of wave attack (SPM 1984a).

Wave diffraction occurs when the energy is transferred in a lateral direction along a wave crest and is most easily seen when an obstacle, such as a breakwater, interrupts a wave train. If diffraction would not occur the region in lee behind the barrier would be left calm, but instead the energy is transported sideways and the waves bend around the obstruction. Also when a wave passes a small opening the diffraction phenomena makes the waves spread in a circular pattern (SPM 1984b).

2.2. Sea level changes

Astronomical tides, movement of ocean currents, land level changes due to volcanic activity or earthquakes, runoff, melting ice and regional atmospheric variations cause short-term change of the sea level. With short-term is meant an interval at which the sea level change can be easily seen or measured, typically at a time span of 25 years. The most characteristic is the change due to the seasonal cycle (Morang & Parson 2002a).

The sea level changes that are looked at from a larger time perspective, thousands and millions of years, are caused by glacioeustatic (uptake or release of water from glaciers and polar ice), tectonic, sedimentologic (compaction of sediment e.g. due to draining of fluids) and oceanographic factors. At the start of the Holocene (15 000 years from present) the sea level was about 100 to 130 m lower than today (Morang & Parson 2002a).

With the sea level rising or falling the result is usually an excessive sediment movement as barriers adapt to the new sea level trying to achieve a new equilibrium (Morang et al. 2002).

2.2.1. Tide

The gravitational force from the moon, and at some extent from the sun, causes the water of the ocean to move with a very long wave period, which is called tide. This results in that the level at which the waves hit the beach changes, since the water level rises and falls one to two times per day. At lagoon inlets this creates tidal currents when the water at one side of the inlet becomes higher than on the other side and a current is created when the water flows from the higher to the lower elevation. How big a tide is varies with the geographic location, with a range between several metres to just a few decimetres (SPM 1984a).

The tidal patterns around the world differs because of that the Earth has an elliptic shape and have large continents, which makes the tide unable to move freely around the globe. There are three basic tidal patterns; semidiurnal when the two highs and the two lows are about the same height, mixed semidiurnal when the high and low tides differ in height and diurnal when there is only one high and one low tide each day (NOAA 2008).

2.3. Littoral sediment transport and longshore sediment transport

2.3.1. Generally about littoral transport

Littoral transport processes is a common name for longshore transport and onshore-offshore transport of sediment (Hung 2012). These transports are generated by winds, waves, tide, currents and other processes active in the littoral zone (Tung 2001). Regarding the basic mechanisms, the sediment transport is in general divided into two groups, suspended load (sediment grains that are supported by turbulence) and bed load (sediment where there is constant contact between the grains) (Hanson 2012a). Most of the times these transport modes are happening at the same time and it is difficult to distinguish them from each other (Hung 2012). When talking about littoral drift it often refers to the actual volume of sand that is transported by the longshore sediment transport (Komar 1998). Important properties of the sediment that affect the transport are the shape of the grains, grain size distribution, density, mineral composition and porosity (Hanson 2012a).

2.3.2. Onshore-offshore transport

Onshore-offshore sediment transport has a direction that is perpendicular to the coastline and is often the most important transport mechanism in the offshore zone (except in areas with very strong tidal currents). Although, depending on the coastal area, in the surf zone both longshore and onshore-offshore transports are significant (Hung 2012). The onshore-offshore transport occurs when waves are travelling towards shallow water of such depth that the water motion affects the sediment on the sea bottom and the sediment grains are moved. The material with the smallest grain size and density starts moving forward and back with the motion of the waves, often in the shapes of uniform and periodic ridges that are parallel to the wave crests. To have an equilibrium in the near shore zone (i.e. having no net accretion or erosion), the average addition and subtraction of sand at a certain point at the sea bottom must be equal (Hung 2012).

2.3.3. Longshore sediment transport

The transport of sediments in a parallel direction to the shoreline is called longshore sediment transport and has a great impact on long-term changes of the coastline. Breaking waves stir up sediment from the sea bottom, which is transported away with longshore currents. The longshore sediment transport is dependent on the angle of the wave crest to the shore and the breaking wave heights. The extent of the longshore sediment transport may vary seasonally (Tung 2001).

Longshore currents are flowing parallel to the coastline, mainly in the zone between the shoreline and the location of incipient breaking waves (see figure 2:2 below) – i.e. in the surf zone. The currents are mainly generated by the wave motion component that is directed along the shoreline in waves approaching the shore from an oblique angle (Tung 2001). Sediment is suspended by breaking waves and the amount of suspended material depends on the breaking type of the wave – plunging waves generally stir up a lot more material than for example spilling waves - and sediment type (Hung 2012). The variable that has the greatest impact on the longshore current velocity is the angle between the coastline and the wave crest of the incoming wave. The breaker height is another important factor that determines the longshore sediment transport rate by affecting the current flow. Even if the speed of longshore currents often may be quite low, they are also of importance to littoral processes due to flowing alongshore for an extended amount of time transporting sediment that has been stirred up by breaking waves (Tung 2001).

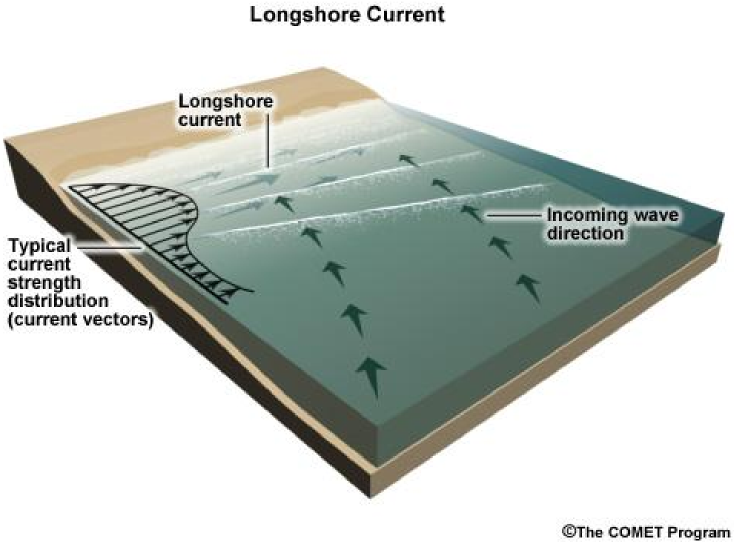

Figure 2:2: Location of longshore currents (National Weather Service 2013)

The velocity of the longshore current varies along the coastline and across the surf zone. When there is an obstacle (such as a groin) that enters the surf zone, the speed downdrift of the obstacle might be lowered a lot, but it increases again with distance (Tung 2001). The transport velocity also varies seasonally since the wave climate, wind direction etc. change during the year (Emanuelsson & Mirchi 2007).

The obliquely incoming waves can be divided into two components – one component along the shoreline and one perpendicular to the shore. The formula for calculating the longshore wave energy flux P_l can be used to calculate the alongshore component of wave power

$$P_l = \frac{\rho g}{16} H_b^2 C_{g,b} \sin(2 \propto_b)$$

where ρ is the water density, g is the acceleration due to gravity, H_b is the wave height when the wave breaks, $C_{g,b}$ is the velocity of the wave group at breaking and $\propto_b$ is the angle between the breaking wave and the shore normal. Furthermore the potential longshore transport rate Q (m^3/s) can be calculated using the formula

$$Q = \frac{K}{g(\rho_s - \rho)(1-n)} P_l$$

where K is a transport coefficient, n is the void space between the sediment particles and ρ_s is the density of the sediment grains. K is an empirical coefficient that differs depending on location and its value should be determined through calibration to take local circumstances into account (Emanuelsson & Mirchi 2007).

2.3.4. Longshore sediment transport components

The sum of the transport from of all wave trains coming on to the shore during a certain time period is called the net longshore transport Q_n, and is accountable for all different transport directions (Tung 2001). If Q_r, is the sediment transport to the right (for example, seen from standing on the beach observing the sea) and Q_l, is the sediment transport to the left, the net transport is $Q_n = Q_r - Q_l$ (Komar 1998). The net transport is generally significantly smaller than the total transport, also called the gross longshore transport, Q_g. This transport component is a sum of all transport to the left and to the right; $Q_g = Q_r + Q_l$ (Hung 2012). In some places the gross transport can be extremely large and the net transport close to none (Komar 1998).

These quantities can be used for different purposes. The net longshore transport Q_n is used to predict erosion on open coasts and to help in designing protected inlets. The gross longshore transport Q_g is used at uncontrolled inlets to predict shoaling rates. Both Q_r and Q_l are used when designing jetties, mainly as the ratio Q_l/Q_r (Hung 2012).

2.3.5. The littoral transport regime

The littoral transport varies over time during the year due to that it is affected by different factors such as wind climate, tidal climate and wave climate. The wave climate is the major influencing factor on the coastal geometry and composition and is directly affected by the wind climate, which is determined by the monsoon seasons. When describing the wave climate along a given coastline it is the statistical distribution of wave characteristics that are observed. Important characteristics affecting the transport of sediment near the beach are wave period, significant wave height, peak period, water level and direction of incoming waves. The direction of incoming waves are often measured with respect to the true north and later on transformed to the local orientation of the coastline (Tung 2001).

Another important factor contributing to littoral transport are currents, which are also connected to previously mentioned factors. Currents can be generated of tide, wind (wind blowing over the water surface creates a stress on the water at the surface and makes it move in the wind direction) and waves. During monsoon very specific wind driven currents can occur. The dominating nearshore current systems are created by waves breaking nearshore or waves coming in with an oblique angle to the shore (Tung 2001).

A combination of forces from waves and currents results in a higher littoral transport rate than if you compare with influence from only waves or only currents, e.g. because waves generally creates suspended sediments (Tung 2001).

2.3.6. Calculating and predicting longshore sediment transport rate

Longshore sediment transport is usually measured in volume units per time, but another way to measure it is in immersed weigh rate I_l, which has the unit force per unit time (N/s). There are a few different ways to predict/measure longshore sediment transport (Hung 2012):

- Using known data from a nearby site and modify it to local circumstances.
- Using historical data showing changes in littoral topography to compute the transport rate. Useful data for this purpose could be, e.g., surveys, charts and dredging records regarding littoral changes. A few indicators connected to the transport rate are shoaling patterns, growth of spits or deposition at an inlet.
- To use measured or calculated data regarding wave conditions to compute the wave energy component directed alongshore, which is connected to the longshore transport rate (Hung 2012).
- Actually measure how much sediment that is transported with e.g. bed-load traps, sediment tracers (coating the sediment with a fluorescent dye or with low-level radioactivity) (Hanson 2012a).

Engineering that involves longshore sediment transport usually has to consider conditions such as magnitude and direction of the sediment transport, long-term and short-term trends of sediment migration, distance that the sand is transported and average and expected shape in the future of the coast line (Hung 2012).

2.4. Coastal lagoon

A coastal lagoon is a body of water that is separated from the ocean by a barrier and connects with the sea through one or more inlets. In the waters of a lagoon a habitat for an extensive variety of marine species and birds is provided and it can also serve as a safe harbour for boats (SPM 1984a). The lagoon is usually oriented parallel to the coast and its depth is typically a couple of metres. During the Holocene the sea level rose which created the coastal lagoons. The water in the lagoon may be mixed by the tidal water, which gives that the salinity of the lagoon water will differ depending of the hydrologic balance. Approximately 14 % of the coastline length in Asia consists of lagoons (Kjerve 1994), which gives a total of 7 126 km of barrier protected lagoons (Morang et al. 2002).

The lagoon and the ocean are separated by a barrier, which is a narrow, extended sand ridge located above the high tide level. The barrier protects the lagoon and the coast behind the lagoon from direct waves from the ocean and it is also one of the most essential recreational and residential regions. Barrier islands are most often found along trailing edges of the migrating continental plates (Morang et al. 2002).

A storm that hits the barrier island can do a lot of damage. During a storm the winds are stronger than in normal weather and generates higher, steeper waves and can also create a storm surge, which raises the water level. This gives that the waves will break at higher parts of the beach and the waves will erode the barrier and carry the material offshore. If the barrier is low or if the storm is severe, the waves can overtop the land and overwash of material will be deposited in the lagoon. The return flow will often erode enough sand to cut a new tidal inlet through the barrier (SPM 1984a).

A lagoon is often used for fishing and aquaculture, and sometimes for salt extraction. If looked at in a long time perspective the lagoon is short-lived, due to sea-level change, tectonic activity and man-made intrusion (such as pumping water, building dams etc.). Surrounding stresses also influences the lagoon, for example forcing from river input, wind stress, tides, precipitation, evaporation and surface heat balance. This affects the quality and the complexity of the water in the lagoon (Kjerve 1994). Lagoons often have a unique ecosystem and function as a nursing, feeding and resting ground for many species. Morphologically are tidal inlets a highly dynamical system that link the nearby coast with a lagoon and the whole system have an important part in the sediment budget of the coastal area, which over time have an impact on the coastal evolution (Tung 2011).

2.5. Mechanisms affecting a tidal inlet

The openings in coastal barriers through which water, nutrient, planktonic organisms, sediments and pollutants are exchanged between the ocean and the lagoon are called inlets. To keep a free passage through the inlet usually has a great financial value, because in many waters behind a barrier there is a harbour located where for example trade and fishing boats can moor. At many inlets dredging adds up to high maintenance costs, to keep the inlet navigable (Morang & Parson 2002b). A tidal inlet has its main channel kept open by tidal flux or river discharge. The inlet size and evolution are related to how large the tide is in the area, the wave climate, the supply of sediment and the structure of the lagoon (Tung 2011).

When looking at the history of an inlet it is often shown that the geometry of the inlet channel varies with time. A rocky headland and a bedrock outcrop are in general significant for a stable inlet that does not migrate. A coast that is dominated by wave induced longshore sediment transport usually has inlets that migrate and barrier spit development (Tung 2011).

The longshore transport is interrupted by an inlet and the sand moving onshore-offshore is trapped by the inlet. Ebb tidal currents carry the sand in the inlet seaward and it forms an ebb-tide shoal when the sand accumulates on the oceanside of the inlet, which is then modified by wave action. The flood-tidal shoal is sand carried by the flood currents and then accumulated on the side of the inlet facing land. Some of the sand will return to the ocean with ebb flows, but some is always lost from the littoral system (sediment in the nearshore zone) and stored in the tidal inlet (SPM 1984a). The throat of the inlet is where the cross section is the smallest and consequentially has the highest flow velocity. The gorge is the deepest part of an inlet and shoals and deltas describe the ebb-tidal sand body situated on the side of the inlet that leads to the ocean (Morang & Parson 2002b). See Figure 2:3 for visualisation.

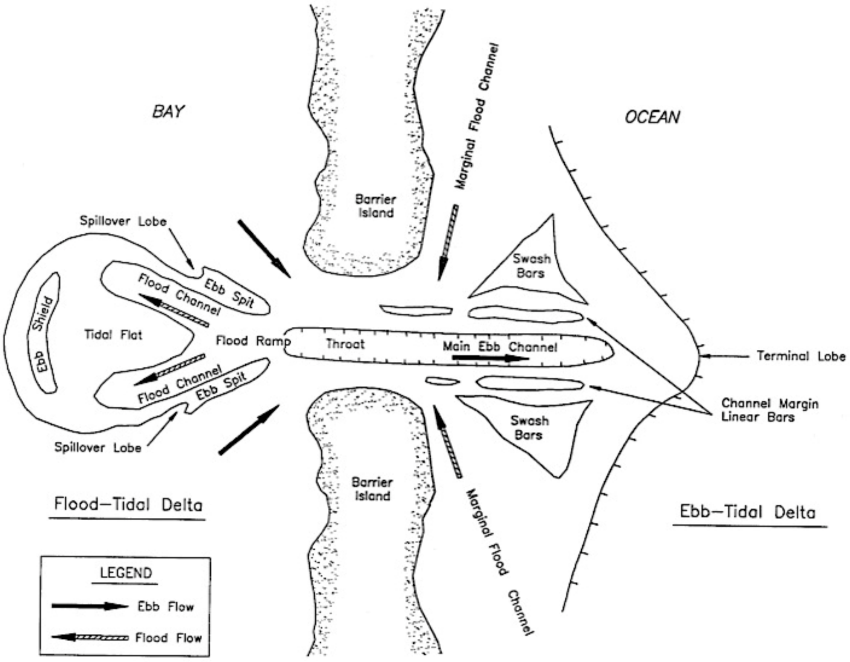

Figure 2:3 Illustration of a tidal inlet with well-developed flood and ebb deltas (Morang & Parson 2002b)

The migration of an inlet depends on interactions of the tidal prism, wave energy and sediment supply. The littoral system is considered to be the primary sediment source that affects the stability of an inlet (Morang & Parson 2002b).

Studies made in Germany and United States shows that the geometry of a tidal inlet and its sand shoals are mainly determined by three factors; tidal range (difference in water level between high and low tide), nearshore wave energy and bathymetry of the lagoon (Morang & Parson 2002b).

2.5.1. Inlet hydrodynamics

At tidal inlets the hydrodynamic conditions can vary from a comparatively simple ebb and flood tidal system to a more complex system with the major forcing effects coming from tide, wind stress, freshwater inflow and wind waves (Seaberg 2006). The main forces that maintain a dynamic equilibrium stable state of a tidal inlet on a sandy coast are the flood currents that carry sediment to the entrance and the ebb currents that try to keep the inlet open by flushing away the sediment (Tung 2011).

A classification for tidal inlets, which has been developed over the years, divides different inlets according to the hydrodynamic processes of the coast. The configuration of the inlet system is not taken into account; instead the classification is based on the main driving hydrodynamic forces of waves and tides. The wave characteristics are created out on the ocean, the wave classification is shown in

Table 2:1 The tide environment, as defined in Table 2:2, depends mainly on how large the tide is in the area and the topography of the ocean floor (Tung 2011, Lam 2009).

Table 2:1 Classification of wave climate (Lam 2009)

Wave energy class	Mean significant wave height H_S (m)
Low wave energy	< 0.6
Medium wave energy	0.6 - 1.5
High wave energy	> 1.5

Table 2:2 Hydrographical classification of coast and tidal inlets (Lam 2009)

Class	Tidal range (m)
Microtidal	< 1
Low-mesotidal	1 - 2
High-mesotidal	2 - 3.5
Low-macrotidal	3.5 - 5
Macrotidal	> 5

A diagram over the classification system, see Figure 2:5, was created with the help from investigation of different coastal areas and divided into five regions based on the ratio of tidal range and average wave height. The ratio between the wave energy and the tidal energy is shown to reflect the geometry of the inlet gorge and the deltas (Tung 2011, Lam 2009).

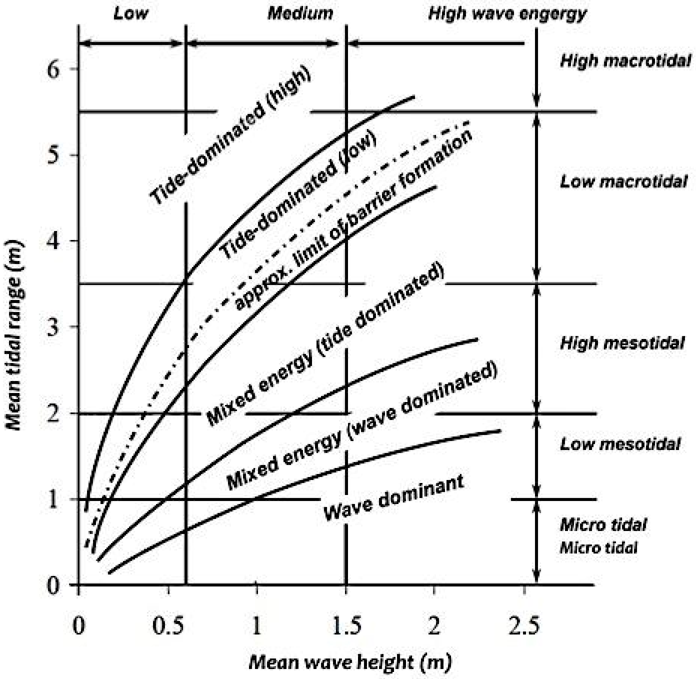

Figure 2:4 Hydrodynamic classification of tidal inlets (Hayes 1975).

The characteristics of a wave-dominated coast are long, narrow and relatively straight barriers with in general separated inlets. Flood tidal deltas are well developed but ebb tidal deltas are small or non-existent, this is due to the dominance of wave energy. At a coast with mixed-energy the inlets are located close to each other and the barriers are short, relatively wide with one end being much wider than the other. The size of the tidal prism exchange that takes place between the ocean and the backbarrier basin will determine the size of the flood tidal deltas. If the ebb tidal deltas are well-developed it indicates a distinctive effect by tidal currents. A macrotidal and wave dominated coast does not have well developed barriers due to the dominance of strong tidal currents, oriented normal to the shore. Stretched ebb-tidal shoals with a main ebb channel are characteristic for a tide-dominated inlet and the sand movement in onshore-offshore direction has effect on in which extent the inlet shore is affected by erosional and depositional changes (Tung 2011).

2.5.2. Tidal inlet stability

Inlets vary in both size and stability, and some have a tendency to change and to migrate while others can be relatively fixed and permanent (Tung 2011). The gorge (also called throat) of the inlet is where flows mix and then later on spread on the opposite side of the inlet. Shallow areas by the inlet mouth on the lagoon or ocean side depend on the hydraulics of the inlet, the wave conditions and the general morphology (Seaberg 2006). Currents, both wave-generated and others, will continuously push sand into the inlet and the flow of the inlet, created by tide, wind and river flow, will carry the sediment seaward or into the lagoon. The relative strength of these two opposing forces will determine the stability and size of an inlet and the relationship between the forces are shown in the Escoffier diagram. An inlet is also affected by severe storms that can both create new inlets and close existing ones (Tung 2011).

When determining the stability of an inlet there are two main aspects to have in mind; the cross-sectional stability and the location stability. The cross-sectional stability attends the area of the narrowest part of the inlet and its equilibrium with the hydraulic environment, which is characterised by the tidal prism. To what degree the inlet can withhold forces that try to disturb the equilibrium is shown through the use of the Escoffier diagram (not presented further in this thesis) and the relationship between the cross-sectional area A and the tidal prism P. The location stability emphasises on the paths of the ebb and flood channels and primarily the ebb delta, which experience changes on the time scale of decades. The ratio between the tidal prism and the volume of littoral drift, P/M_{tot}, describes the location stability (Tung 2011).

The relationship between the cross-sectional area of the channel A and the tidal prism P is written $A = CP^q$, where C and q are empirical parameters, and is called the A-P relationship. The relationship is based on the model that the equilibrium area of an inlet is defined by the balance between the littoral or longshore transport and the capacity of the entrance flow at ebb-tide (Tung 2011).

The stability of a tidal inlet can also be determined by the relationship P/M_{tot}, where P is the spring tidal prism and M_{tot} is the total annual littoral drift reaching the inlet. The relationship states the relative strength of tidal currents to erode or flush out the sediment that has been deposited by longshore transport in front of the entrance of the inlet. The rating of the inlet stability is good, fair or poor, as shown in Table 2:3. The sand bypassing by tidal flow is also seen in migration of channels and bars in downdrift direction and accretion of sand bars (Tung 2011, Seaberg 2006).

Table 2:3 Inlet bypassing and classification of inlet stability (Tung 2011, Seaberg 2006)

P/M_{tot}	**Channel stability**
< 20	An unstable channel that is more of an “overflow channel” that can be closed during storms and not a permanent inlet. Poor stability
20-50	A highly variable channel in location and area, with multiple channels possible. To maintain a navigable depth is dredging and jetties generally required. Poor stability
50-100	Usually a clear main channel, but a rather large ebb shoal. Fair to poor stability
100-150	A clear main channel with a developed seaward bar. Fair stability
> 150	A stable channel with little bar and good flushing. Good stability

2.6. Coastal protection

The major interests when it comes to shore protection are the reduction of the damage done by storms, adjustment of the coastal erosion and the ecosystem restoration (Basco 2003). It is also possible to divide the problems into four general categories, in a coastal engineering point of view: shoreline stabilization, backshore protection, inlet stabilization and harbour protection (SPM 1984c). When a wave hit a beach a dynamic response to the wave energy is made and the beach adjust its profile to be able to spread the wave energy in the most efficient way. There are two key types of responses: the response to normal wave conditions and the response to storm conditions. At normal conditions one of the beach’s natural defence mechanisms is the sloping nearshore bottom at which the wave breaks and the wave energy is dispersed by the turbulence created in the water and by sediment transport caused from the turbulence. By depositing beach sediment further out from the shore, the surf zone is widened and the waves will break further away from the beach, which will increase the beach protection (SPM 1984a).

A beach response to storm conditions is often made through severe measures, for example by sacrificing an extensive amount of the beach due to larger waves and storm surges that carry a larger amount of energy, which is not dissipated in the surf zone (SPM 1984a). The damage done by storms is divided into two mechanisms, coastal flooding and wave damage. A storm is a short-term erosional event that creates an elevated water level, a storm surge, which floods the land and damage coastal property. The elevated water level also results in that the high wave energy is brought inland and damages upland development. The long-term coastal erosion is made through wear and tare caused by mankind and nature. A more modern look on the protection of the shore also includes restoration of damaged or ruined environmental resources such as wetlands, reefs, nesting areas, etc. (Basco 2003).

Key elements when deciding what action to take due to erosion of the coastal area is planning and timing. The main considerations to see to are the economical, technical, environmental, legal, institutional, social and political aspects. The economic factors to look at are the initial cost and the cost for operation and maintenance, but also to see to the economic sustainability (GNP), financing, cost recovery and the economic viability of the project. The technical factors that should be reviewed are the level of skills and availability of people, the availability of material, equipment and data (Hanson 2012b).

There are five different alternatives to choose between when it comes to making a decision regarding how to manage a shore protection project; accommodation, protection, beach nourishment, retreat and the choice to do nothing at all (Basco 2003). With accommodation the beach structures are adapted to the new conditions, this is done by development of the structures and no stabilization measures are taken to stabilize the surrounding land. In areas with a high degree of development the choice to protect is usually taken, with possible high costs for building protective structures but with a high economic benefit. In an area with a lower degree of development a retreat could be the option, then the structures along the coast will be moved further inland. A loss of land and investments as well as the major financing and social implications are the main disadvantages, but no investment in building shore protection structures have to be made (Hanson 2012b).

There are three different types of structures to chose between; Hard structures, intermediate structures and soft structures. Hard structures could for example be a groin or a detached breakwater. Examples of intermediate structures are a revetment, a sea wall and a bulkhead. As soft structures different measures like beach fill, protective beaches and armouring vegetation are considered (Hanson 2012b).

2.6.1. Coastal protection structures

When the protection from beaches and dunes are not sufficient, manmade structures will protect the buildings on the backshore and keep the coast from eroding. The structures are divided into two sections, structures that prevent waves from reaching a harbour area (e.g. breakwaters, seawalls, bulkheads and revetments) and structures that are used to retard the longshore transport of littoral drift (e.g. groins and jetties) (SPM 1984a).

When a decision is to be made regarding what kind of structure to build and how to design it some parameters must be known, such as hydraulics (wind, waves, currents, tides, storm surge or wind setup and basic bathymetry), sedimentation (the littoral material and processes, sediment classification and characteristics and changes in shore alignment) and considerations regarding the navigation (SPM 1984c).

2.6.2. Groin

The emphasis regarding coastal structures in this thesis will be on groins, since it is the structure that was built to stabilize Thuan An inlet.

A groin is designed and built to hinder longshore drift, with the purposes to build a protective beach, to retard erosion of a beach or to prevent the sediment from reaching a harbour or an inlet. A groin is most commonly constructed perpendicular to the shoreline and is a narrow structure designed with varying lengths and heights see Figure 2:5. A groin construction is built to manage intruding sediment on the updrift side of an inlet, for reduction of the loss of beach fill at the banks of an inlet that have strong tidal current or placed on the downdrift side of a harbour breakwater or jetty. Even though the groin is one of the oldest coastal protection structures there are no systematic method for designing, only a few rules of thumb, which have led to that many structures built does not function properly and many countries precludes the use of groins (Basco 2003).

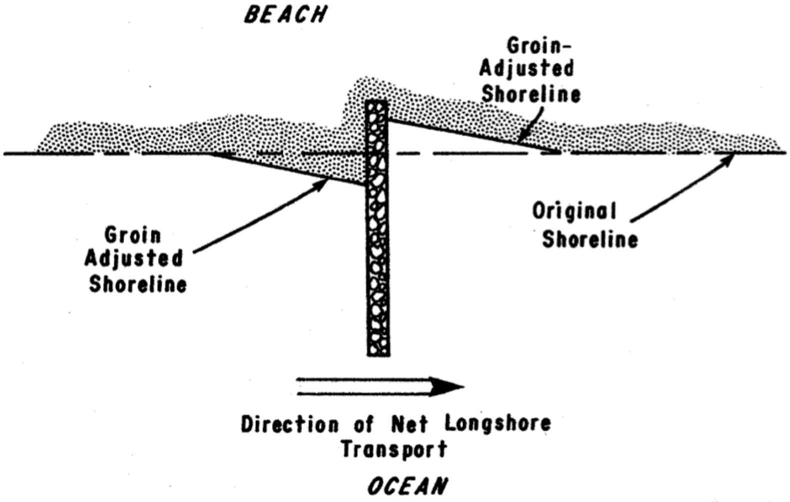

Figure 2:5 A groin with general shoreline adjustment for direction of net longshore transport (Basco 2003)

The groin function is to block some of the sediment that is transported along the shore and the sand accumulates on the updrift side of the groin. The sedimentation on the updrift side results in a reorientation of the shoreline and this in turn changes the angle between the beach and the incoming direction of the dominant wave train. On the downdrift side the sand transport is greatly reduced or eliminated by the groin, which causes the beach to erode. The current pattern that move the sediment on the leeside of the groin is induced by wave diffraction, mean water-level setup gradient and structure induced currents (Basco 2003).

Bypassing of sand can be done through overpassing the top of the groin or endpassing by go around the seaward end of the groin. Overpassing is allowed when just enough sedimentation has settled on the updrift side to allow the water level to rise and carry sediment over the groin. When endpassing occurs the accumulation of sand on the updrift side has built seaward until the breaker zone is moved so far out from the beach to allow sediment to bypass the groin. Tide and wave climate makes the water level change frequently, which enables bypassing over the groin and at the end of the groin depending on how the beach profile moves (SPM 1984c).

When designing a groin there are three key factors that should be kept in mind; the bypassing of sand at the tip of the groin, the permeability of the groin and the longshore transport of sediment. For seaward sand bypassing it is the ratio of groin length to surf zone width that is the key factor for designing (Basco 2003). The length of the groin should be 40-60 per cent of the average width of the surf zone. The height of groin is determined from the depth at the groin head, the tidal range and the characteristics of the wind, and the height is an important parameter related to seaward rip currents. The most common material for a groin to be built in is stone, the core consist of smaller stone material and has a surface armour of large stones (Tung 2001). The profile of a groin consists of an onshore section, a sloping middle section and a horizontal seaward section, see Figure 2:8. The onshore section is defined as the elevation of the present beach berm, the sloping section is determined to have the same slope as the beach face in the swash zone and the seaward section is set to the same elevation as the mean low water (MLW) or lower. Most of the groins are straight structures that are constructed perpendicular to the shoreline, but there are other possible planform shapes like T-, L- or Y-shaped. A terminal groin is constructed on the updrift side of an inlet to control the amount of beach nourishment lost to the inlet and to keep the inlet channel open for navigation. The construction of a groin system has a controlling factor in the ratio of the spacing between two groins and the groin length, which should have a value of 2-3 (Basco 2003).

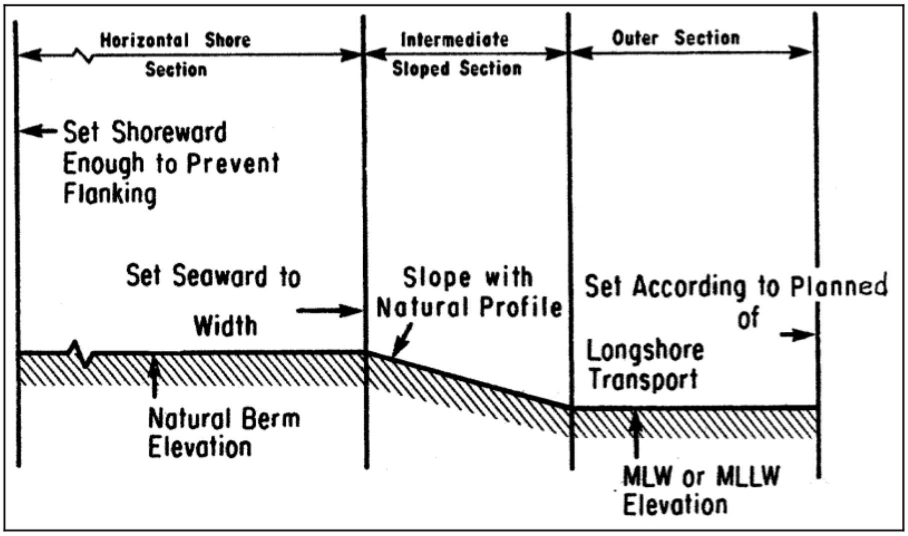

Figure 2:6 Groin profile (Basco 2003)

A groin should not be considered when the tidal range is large, when the dominant type of sediment transport takes place cross-shore, when the construction will be too long or impermeable which causes sand to be flushed seaward, or if strong rip current are created which makes it unsafe to bathe. A more modern look at groin design is that of not trapping the sand on the updrift side of the groin but to allow sand to bypass the groin (Basco 2003).

A beach fill should always be included in the design, to avoid erosion of adjacent beaches. A modern, numerical simulation model (e.g. GENESIS) should be used to get an approximation of the shoreline change and to evaluate the minimum dry beach width during storm events the cross-shore sediment transport should be modelled (with e.g. SBEACH) Basco (2003.).

2.6.3. Jetty

A jetty is primarily used to stabilize inlets and their navigational channel, to shield boats from the forces of waves and to minimize movement of sand into the channel. To have complete protection of the inlet there are often two jetties built, one on each side of the inlet channel. A jetty can be constructed by timber, steel concrete or quarrystone, and most of the larger jetties are constructed with armour of quarrystone and a core of less permeable material to prevent sand from passing through. The major negative impact made by a jetty is the erosion of the downdrift beach and in some projects pumping sand from the updrift side to the downdrift side of the jetty solves this problem. Another effect of pumping sand is that the shoaling of the inlet channel may be reduced, because there will be a smaller amount of sand on the updrift side that can build up and eventually move around the jetty and into the inlet channel (SPM 1984a).

3. The Central Coast of Vietnam

This chapter concerns the study area of Thuan An inlet, the city of Hue and Thua Thien-Hue province and introduces its history and situation today, climate, geologic features, hydrology, sedimentation, morphology and sediment transport. It also shortly mentions the different mechanisms related to the mechanics of the lagoon.

3.1. General historical information about the area

3.1.1. General information about the Thua Thien-Hue province

The Thua Thien-Hue province (see Figure 3:1) is located in the central part of Vietnam, 1060 km north of Ho Chi Minh City and 660 km south of Hanoi. The provinces Quang Tri in the northwest, Quang Nam and Da Nang in the southeast surround it and to the southwest of the province is the border to Laos. To the northeast lays the South China Sea, sometimes also called East Sea (Tung 2001). The capital of the province is Hue city. Circa 1 100 000 people live in the whole province (General statistics office of Vietnam 2013). The people of the province mainly live from small industries and handicrafts, tourism and services, agriculture, forestry, aquaculture and fishery (Lam 2002). Hue is an important ancient city designated by UNESCO as a cultural heritage of mankind, due to its amount of historically important architectural works, among others from the Nguyen Dynasty (1802-1945). It was also the capital of Vietnam during the French colonisation between 1887 and 1945 (Tung 2001).

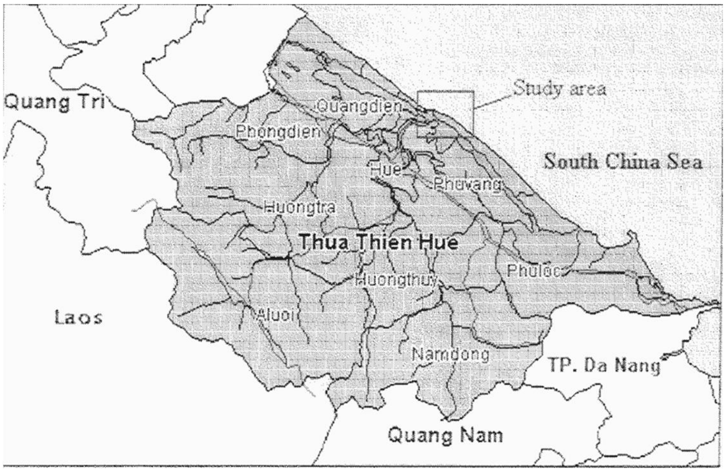

Figure 3:1 Map of the Thua Thien-Hue province (Tung 2001 - modified)

Thuan An inlet is located near the Thai Duong Ha village in Thuan An commune and borders Hai Duong commune in the west, and Phu Thuan commune in the east, see Figure 3:2 (Tung 2011).

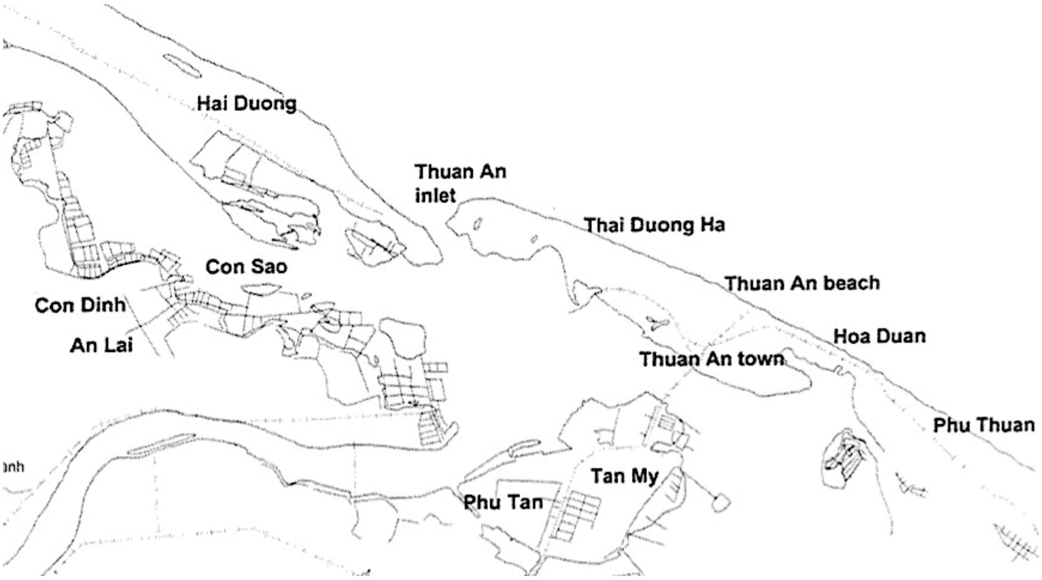

Figure 3:2 Map of the study area around Thuan An inlet, from 1987 (Tung 2001)

3.1.2. General history of the area around the Tam Giang-Cau Hai lagoon system

People started settling in the area around the Tam Giang-Cau Hai lagoon a long time ago. The first known settlers are the Chàm people who are known from ancient history about this area. During the immigration of the Viet people from the north and the south, the Chàm people moved away. Therefore, most historians agree on that the villagers around the lagoon originate from among others the Thanh Nghe Tinh people migrating from the north, but also from people migrating from the south (Brzeski & Newkirk 2000).

The Viet people started immigrating from the north around year 1010 and then the immigration increased the following decades. Immigration from the south occurred later, starting around 1788, when the city that today is called Hue was taken over by Emperor Nguyen Hue. He took over the citadel in Hue and appealed to the Viet people living in Quy Nhon to come to Hue and support him (Brzeski & Newkirk 2000).

Vietnamese people around the lagoon generally settled down either on land to live on farming or on boats to do fishery. The people living on fishery are also called the Sampan people and they have for many generations lived on boats and raised their families there. Since the society in many aspects has been centred on landowning and rice growing, they have always been outside the mainstream society. They have for many generations been treated as lower class people by the mainstream society. In recent years the government has tried to make them less isolated by registering them with communes and relocating many of them to live on land instead. Most of the Sampan people are still though outsiders in society with less access to education, healthcare and other social services (Brzeski & Newkirk 2000).

At present time the lagoon is of high economic value for the area because of fishing and aquaculture and it can be shown by the area and inhabitants; the lagoon system is about 30 % of the total area of the province but 80 % of the population lives there. The area also has a large potential for tourists and for building resorts (Hung 2012).

3.1.3. History of livelihood in the lagoon

The origin of fishery in the lagoon is connected to the background of the Sampan people. According to the legend one sampan family established in each different part of the lagoon and only fished there. As family generations passed by they formed organisations that regulated the fishing in the claimed area and these organisations were called *Van*. These organisations were originally a clan of related fishers, but they eventually became groups divided by geographical area, though still loosely related to each other or bound by close friendship. The families started to create groups after which fishing gear they were using and normally 2-7 families using the same gear went together to form a subgroup in the Van. After a while the bond between the fishers in the same Van was a combination of marriage, blood relation, fishing area, fishing activity and which gear they used (Brzeski & Newkirk 2000).

As a number of Sampan people got the money, desire and access to land some of them settled down on land, not leaving their fisher life completely though. Many of them got into agriculture, but also started to get rights to their own fishing grounds where they started to use fixed fishing gear such as bottom nets, fish aggregating devices and fish corral. At this time, these fishing rights were sold at annual auctions. In this system the fisher who won the auction for a certain ground one year had a priority for the same ground in the next year’s auction. With this system the same family could have the rights to the same fishing ground for many generations. Eventually, the auctions stopped and the rights to the fishing grounds were held for life and were inherited. The auction price was exchanged to an annual fixed tax. This system is still the system today and the Vietnamese government charges a tax relative to the potential production of the fishing ground (depending on among others location of the fishing ground and which fixed fishing gear that is used). Still today there are a large number of Sampan people living on boats fishing with “small” gear such as hook and line, dragnet and pushnet, not having fixed fishing grounds (Brzeski & Newkirk 2000).

Earlier, the area of the lagoon was divided, in a manner similar to land plots, and farming villages were managing the lagoon area. The managing village controlled the fishery and collected taxes from the fishermen being active in the specific fishing ground connected to the village. Van managed the fishery out in the lagoon in these areas connected to a certain village, and managed the collection of taxes, solved conflicts between fishers active there, improved the protection and management of aquatic resources and prevented exploitation by fishers not belonging to the area. Fishermen were supposed to follow both governmental rules and Van rules. With this system Van had a very important role managing and administrating the fishery and preventing breaking of the rules. During the French colonisation the Van system was kept because it was considered very effective. However, in the mid-seventies the relationship between Van and the managing communities were cut off and the Van lost their function since the communities were not controlling the fishery in the lagoon, self-management was not tolerated anymore (Brzeski & Newkirk 2000).

In modern times, the aquatic resources in the Tam Giang-Cau Hai lagoon are administrated mainly by the Department of Fisheries, Division of Protection of Aquatic Resources, District Bureaus of Agriculture and Fisheries and the provincial People's Committee (PC), district PC and commune PC. Most of the regulations concerning aquatic resources are managed by the national government. Local enforcements of these national regulations are most often not cared about by the local governments and the previously mentioned institutions lack coordination. This leads to that conflicts and violations according to the fishery in the lagoon are often not solved in a satisfying way (Brzeski & Newkirk 2000).

3.1.4. The Tam Giang-Cau Hai lagoon today

The Tam Giang-Cau Hai lagoon is the largest lagoon in Southeast Asia and approximately one third of the province' population earn their living out of the lagoon, including many Sampan communities. A few Sampan communities are still living a nomadic life and they are almost only dependent on small-scale fisheries to make a living. The main things that people living around the lagoon work with are aquaculture, agriculture, capture fisheries, forestry and livestock (IMOLA 2006).

Especially the fishery and aquaculture has an important role in the area due to its long coastline and the existing lagoon, and particularly aquaculture has grown in recent years. Aquaculture has been considered an important economical activity and also a way to get out of poverty, it is said to have increased the income of many people living around the lagoon. The main part of aquaculture started in the lagoon approximately 25 years ago and regards shrimp farming, although several marine, brackish and fresh water fish species are also fished in and around the lagoon. Agriculture is also a traditional occupation for many people living around the lagoon, and it is believed to provide a stable income to many people living around the Tam Giang-Cau Hai lagoon or one of the rivers falling out into it (IMOLA 2006).

The area around the lagoon is at risk due to annual flooding, water pollution and over-exploitation (IMOLA 2006). Flooding can have severe consequences for people due to the loss of habitations, crops, properties, livestock and destroyed infrastructure and can also cause pollution of the environment. New inlets opening or existing inlets closing, could give e.g. changed ecological and physical properties of the lagoon (such as changed water environment and disturbed ecosystems) (Tung 2011), which could change circumstances for fishing, agriculture, aquaculture, navigation and other activities of the lagoon (Brzeski & Newkirk 2002). Many fishing villages use the inlets as navigation channels and fishing boats can also take shelter in the lagoons during typhoons. If an inlet is closed it can also affect the water exchange and circulation of the lagoon, and thus also the water quality, which can have an impact on species living there and the biodiversity. The water salinity can change and it is affecting especially the aquaculture by fluctuating, some crops grow better and some grow slower depending on the salinity of the water. Some types of aquaculture can also suffer if the turbidity of the water is changed (Tung 2011).

3.2. The Tam Giang-Cau Hai lagoon system and its inlets

3.2.1. General information about the lagoon system

The valley of Hue contains the Tam Giang-Cau Hai lagoon system that is divided into four smaller lagoons; the Tam Giang, Thanh Lam, Thuy Tu and Cau Hai lagoon (Borsje 2003). Together they make the biggest lagoon system in South East Asia with an area of approximately 216 km^2, a length of 68 km (Tung 2001, Lam 2009) and a maximum width of 10 km (Hung 2012). The water depth is between 1-5 m in the Tam Giang lagoon and 1-3 m in the Cau Hai lagoon. In the channels close to the Thuan An inlet the water depth is at its deepest, between 5-10 m (Lam 2009). See table 3:1 for characteristics of the different lagoons in the system.

Table 3:1 The characteristics of the Tam Giang-Cau Hai lagoon system (Lam 2009)

Lagoon	Area (km^2)	Length (km)	Average width (km)	Average depth (m)	Tidal inlet
Tam Giang	52	27	2	2	Thuan An
Thanh Lam	25	5	5	0.5-1.5	Hoa Duan*
Thuy Tu	35	25	1.5	2	No inlet
Cau Hai	104	15	7	1-1.5	Tu Hien

*The Hoa Duan inlet is currently closed

There are three subdivisions of coastal lagoons, choked, restricted and leaky lagoons. The Tam Giang-Cau Hai lagoon system is a restricted lagoon because of its orientation, the distinct barrier between the lagoon and the ocean and the number of inlets. A restricted lagoon has a well-defined tidal circulation, is influenced by winds and is mostly vertically well mixed (Kjerve 1994). The water in the lagoon system is brackish and 90 % of the water inflow from rivers is received from the Huong River basin, which has a catchment area of circa 4400 km^2. The lagoons are all connected to a system and have two inlets connected to the sea; the Thuan An inlet which is the northeast one and the Tu Hien inlet in the south, see figure 3:3 (Lam 2009). When the river flow is low, during the dry season, the water supply to the lagoon is reversed and water comes in from the sea by tide through Thuan An and Tu Hien inlets (Hung 2012).

Outside the lagoon system is the longest stretch of sandy coastline in Vietnam, 128 km long located on a barrier island with an average width of 20 kilometres. The dunes are of white sand, which contains heavy minerals indicating their source to be Huong River (Inman & Harris 1966).

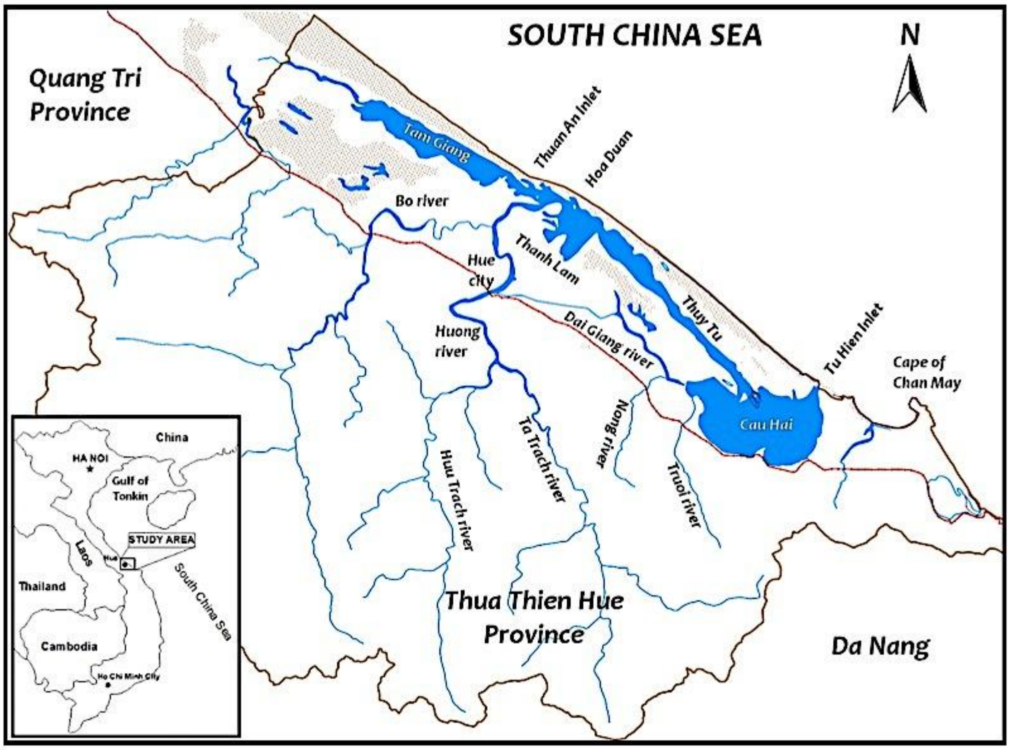

Figure 3:3 The system of lagoons, inlets and rivers at Thua Thien-Hue province (Tung 2011)

3.2.2. History of the inlets of the lagoon

Thuan An and Hoa Duan inlets

There have been several different inlets to the lagoon over the years. During many centuries the Tam Giang-Cau Hai lagoon system had only one inlet, located in the south, called Tu Dung (today called Tu Hien) (Hung 2012). The Thuan An inlet in the north, which today is the main inlet, was opened in 1404 from a natural breakage of the sand barrier due to a severe typhoon followed by elevated water levels (Inman & Harris 1966). Some different configurations of the Thuan An inlet can be seen in figure 3:4 below. The Tu Hien inlet was the main inlet until Thuan An was opened and when it had opened the Tu Hien inlet started a trend of accumulating deposit and closure. In the year of 1500 the Hoa Duan inlet opened, located just south of Thuan An inlet, which caused the Tu Hien inlets to become smaller and finally to close due to sand migration. Attempts were made to keep the Tu Hien inlet open by dredging it and by closing Thuan An, but it did not succeed (Lam 2009).

Between the years 1868 and 1883 both the Huong River and the Hoa Duan inlets was closed as a protection from French battle ships, but in 1883 they were opened again for navigation. A breach occurred in 1897 at the Thuan An inlet and this lead to that the Hoa Duan inlet became smaller and Thuan An became the primary one. Thuan An was closed 1903 but was opened again in 1904. In that year the Hoa Duan inlet was almost closed due to a serious typhoon and in the year 1909 it was completely closed. Salt intrusion from the Thuan An inlet started to become a problem for the agriculture and in 1928 French engineers started to build a closure dam and a dyke system around the lagoon to prevent this. The closure dam was damaged many times between the years 1928 and 1953 by floods and it had to be restored (Lam 2009).

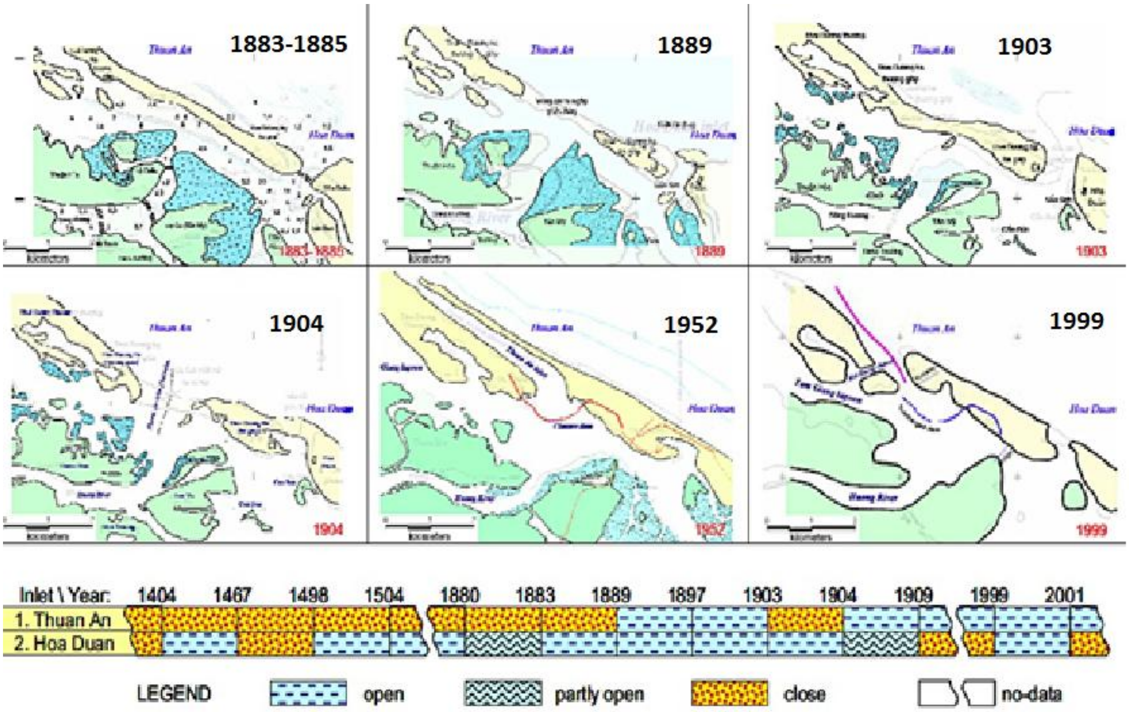

Figure 3:4 Different configurations of the Thuan An inlet during different years (Lam et al. 2007 - modified)

The Thuan An port was built in the 1960s by the US Army and the inlet was dredged and a major part of the closure dam was removed to be able to access the port. The inlet was stabilised by a 200 m long steel jetty in 1969, which lasted approximately for ten years. When the jetty was no longer there the inlet became unstable and the channel morphology was frequently changing (Lam 2009).

As a measurement against the on-going erosion of the coast outside the Thuan An inlet, a groin field was constructed in 1997. Five groins were built just south of the narrowest part of the inlet. Though already after one year after they were constructed they were damaged and lost their function, this because of unsuitable scour protection and filter layer around the toe. Another problem was that the stones in the trunk of the groin were too light; they could not withstand the forces from currents and wave attacks (Tung 2001). This groin field was designed without conducting a scientific pre-investigation (Hung 2012).

It has happened during the last centuries that the small sand-barrier at the Hoa Duan strait (4 km south of the Thuan An inlet) has been breached, creating an inlet there as well. Afterwards it has been closed but then it has become open again (Borsje 2003). For example - severe breaches in the sand barriers occurred in November 1999 caused by extreme floods and this opened an inlet at Hoa Duan. These rapid changes together with severe coastal erosion led to modifications of the inlet and also to a change of direction of the inlet channel. In September 2000, after failing once the same year, the Hoa Duan inlet was completely closed with concrete blocks and sandbags (Lam 2009). The authorities want it closed to see if it has an impact of the stability of the Thuan An inlet, but it is likely to breach again. The Tu Hien inlet is due to the long distance to the other two acting independently (Borsje 2003).

Today the Thuan An inlet is the main one. The Tu Hien inlet is open but has changed over the years and is lately becoming shallower and narrower, which is why it is expected that it will close eventually (Lam 2009). Figure 3:5 shows a part of Thuan An inlet as it looks at present time.

Figure 3:5 Thuan An inlet photographed from the south, January 2013 (Photo Eva-Lena Eriksson)

The Tu Hien inlet

As described before, the Tu Hien inlet was the main inlet to the lagoon for many years and it started to decline when the inlet of Thuan An was opened in 1404. The northern part of the Tu Hien inlet consists of sandy beach and the southern part consist of rocky shore and is sheltered by a headland. This implies that wave induced longshore sediment transport mainly come from the northwest direction of the inlet (Lam 2009).

On account of river floods, waves and longshore transport the inlet is frequently changing and migrating along the coast between Loc Thuy and Vinh Hien in a morphological time cycle of approximately nine years. During this period it is also closed more than fifty percent of the time. The cycle starts with a breach of the sand barrier at Vinh Hien during an extreme river flood, creating a new inlet. At these first stages of the cycle the inlet is normally around 200 m wide and 3 m deep. Due to the longshore sediment transport in a southeast direction the inlet migrates in that direction until it reaches the headland at Loc Thuy, then it starts to decline and then closes, and so does the morphological cycle. At this point the inlet has a shape of a shallow and narrow channel that is approximately 1 m deep, 4 km long and 50 m wide (Lam 2009).

The Tu Hien inlet has caused several problems for the people living around the lagoon during periods when it has been closed; for example problems concerning navigation and fishing, but also affecting the ecosystem of the Cau Hai lagoon (Hung 2012).

3.3. Physical Setting

3.3.1. Rivers discharging to the lagoon

Five rivers, O Lau, Bo, Huong, An Nong and Truoi, flow into the lagoon system coming from the Truong Son Mountains (Tung 2001). There are many stations by the rivers measuring the flow discharge and also by the inlets there are measurements being made at different locations to measure water level, sediment transport, flow discharge, salinity etc. The river flow varies with the rainfall and monsoon cycle. From when the Northeast monsoon starts in September until December it is flood season and during this period 70 % of the annual river flow takes place. Effects of the later part of the Northeast monsoon can also cause small floods in January and February (Lam 2009).

The total catchment area of the whole river system in Thua Thien province is 4000 km^2 and the total runoff that is discharged into the lagoon by the rivers is estimated to be 6 km^3 per year. Fresh water is coming into the lagoon via the rivers and saline water enters the lagoon via the two inlets Thuan An and Tu Hien (Tung 2001). Huong River (also called Perfume River) is the major river and it enters the lagoon system nearby the Thuan An inlet, and its delta forms a partial separation between the two north-western lagoons in the system (Inman & Harris 1966).

The rivers carry with them a lot of sediment to the lagoon. They also carry plankton and algae, which makes good conditions for shrimps, fish, crabs and other species living in the lagoon water (Tung 2001). The sediment concentrations in the main rivers are usually around 50-150 mg/l but during floods the concentrations increase a lot. The rivers all together carry a sediment load to the lagoon of about 1.0-1.7 million m^3/year and approximately 80 % of this load is transported via Bo and Huong River (Lam 2009).

3.3.2. Climatology

The changes in regional climate affect the Tam Giang-Cau Hai lagoon in different ways, e.g. rainfall, wind strength and wind direction, river flow and temperature are factors that change with season (Tung 2001). Vietnam and the South China Sea are located in the tropical belt of the Northern Hemisphere and in comparison with other belts the tropical belt is the one with the highest solar radiation on Earth. The area is also a typical tropical monsoon zone and the seasonal changes of atmospheric circulation that results in a weather system dominated by the two yearly monsoons, the northeast monsoon (or the winter monsoon) from September to March and the southwest monsoon (or summer monsoon) from May to September. The northeast monsoon has a large impact on the northern parts of Vietnam and the southwest monsoon has high intensity in the central and south regions of Vietnam (Hung 2012).

The tropical monsoon climate has a great impact on the morphology of the inlets with its seasonal variation of currents, wave climate and river flow (Lam 2009). In the area around the lagoon there are also approximately five tropical typhoons every year between June and November and over 80 % of the local flooding is a result of these typhoons and the storm surges and heavy rainfall that they cause (Tushaj 2009).

The salinity of the lagoon also varies with the seasons. During flood/rainy season it is the flow from the rivers that is dominating the lagoon leading to a low salinity of approximately 0.02-0.2 %, the water is nearly fresh. During this time the water is also assumed to be fresh in the inlet. In the dry season the flow from the rivers is very low and the lagoon is mainly filled with seawater, and salt water is penetrating the rivers deeply upstream. The water in the inlets is mixed at this time and has a salinity around 29.4-32.4 ‰ (Lam 2009).

The Northeast Monsoon

The northeast monsoon is the rainiest season of the year, called the “flood” or “rainy” season. During this period more than 70 % of the Huong river basin’s precipitation (which is approximately 3 300 mm/year) takes place. This is also the most common period for tropical cyclones to occur, which also adds on to the rainfall in the river basin (Lam 2009).

Strong winds can occur, most often northern or north-western winds, with speeds up to 18 m/s. These winds affect the area where Thuan An river is located and begins in October, with its peak in December and January. The direction of the currents during the peak of the northeast monsoon is to the southwest, which produces strong surface currents along the coast (Inman & Harris 1966).

The Southwest monsoon

In the summer the dominant wind is southwest offshore. Rain during this period is often topographically driven. In coastal areas the climate becomes hot and dry; river flow and rainfall diminishes considerably, giving it the name the “dry” or “low flow” season (Lam 2009). In May and June the southwest monsoon reverses the currents (Inman & Harris 1966).

3.3.3. Geology and geomorphology

Around 70 % of the river basin area is mountainous and hilly and the rest is narrow lowland plain. Geologically, the area in and around Hue consists of hard rock. It is the Annamite Massif that stretches southwards from central Asia down to Vietnam, consisting of coarse-grained intrusive rocks (e.g. granite), largely metamorphosed sedimentary formations (e.g. limestone, schists and quartzites) and volcanic rocks (e.g. basalt and rhyolite). Granite constitutes the majority of the massif (Inman & Harris 1966).

Outside of Hue is the longest reach of sandy coastline in Vietnam with a length of 128 km (Inman & Harris 1966). Approximately 70 km consists of sandy beach supported by sand dunes and the rest of the coast has sandy beaches between rocky headlands or rocky coasts (Lam 2009). The valley that Hue is situated in has an average width of 20 km and a lot of sediment is carried to the Tam Giang-Cau Hai lagoons by the rivers that enter the sea through the valley (Inman & Harris 1966). Morphological changes are naturally affected by changes in precipitation and consequently also changes in runoff and river flows. Also the longshore sediment transport is an affecting factor. For example during the Northeast monsoon when runoff and river flows are large remarkable morphological changes may happen that can e.g. change the structure of the lagoon inlets (Tushaj 2009).

3.3.4. Sediment transport regime

The littoral transport regime in the coastal area outside of the lagoon is affected by different factors such as tidal climate, wave climate and wind climate (see chapter 2.3). The area outside of the Tam Giang-Cau Hai lagoon is affected by the tropical monsoon climate obtained by the West Pacific Typhoon regime, which provides the area with a large amount of rainfall and also typhoons occurring from time to time. There are two main monsoons – the northeast (winter) monsoon and the southwest (summer) monsoon. During the winter monsoon (from September to March) the net longshore sediment transport is in a southeastern direction and during the summer monsoon (June to August) it is in a northwestern direction. The measured longshore current velocities are between 0.3-1 m/s (Tushaj 2009).

In the coastal area outside of the Thua Thien Hue province the tidal regime is rather complicated – it changes from being semi-diurnal with a small tidal amplitude of 60-120 cm between Quang Binh and Thuan An to having a smaller tidal amplitude of 30-50 cm outside the Thuan An inlet. South of the inlet the amplitude is gradually increasing again reaching an amplitude of 55-110 cm outside of the Tu Hien inlet, i.e. the whole coastal area outside the lagoon is microtidal. The tidal waves go from south to north and the tidal velocity at flood tide is 0.5-0.7 m/s and at ebb tide 1-2 m/s (Tung 2001). A stronger tidal force increases the onshore-offshore littoral transport and thus also affects the sediment transport pattern that is occurring. Outside of Thuan An is the tidal current relatively small, around 0.25-0.30 m/s at a depth of 10-15 meters, and it reduces when the depth becomes larger (Tung 2001), thus the tidal currents are not the major impacting force on the littoral transport in this area.

The coast outside of Hue is 120 km long and lies in a northwest – southeast direction. The Thuan An inlet divides the coast side into two parts. One part is limited by the Cua Viet estuary in the north and by the Thuan An inlet in the south. This section is mainly built up by sand beaches and sand dunes and is fairly geometrically homogeneous and also pretty stable with little erosion/accretion. An exception is Hai Duong where the coastal erosion was around 4-5 m/year until 1999 when an extreme river flood occurred and it increased to 8-15 m/year. The erosion at Hai Duong can be contributing to the changes in morphology at the Thuan An inlet. The second part stretches from Thuan An down to the headlands of the Linh Thai mountain and it consists of a sand barrier. South of this part it continues down to the headlands at Loc Thuy and this part is also a sand barrier (Lam 2009).

3.3.5. Measuring stations in the lagoon area

The long-term tidal water measurements of the level of the coastal waters outside Hue are made in Con Co, Da Nang, Cua Tung, Cua Viet, Kim Long and Phu Oc. All the stations make hourly observations, except for Con Co where observations are made every 6 hours. At various locations nearby the inlets, short surveys measuring tidal levels and currents have also been made (Lam 2009).

Sediment samples have been taken at several places on the coastline outside of the Tam Giang Cau-Hai lagoon. The top layer of sand on the shore (down to a depth of 18 m) consists mainly of medium to coarse sand with the dimensions D_{50} = 0.41 mm, D_{90} = 1.40 mm and a solid density of 2650 kg/m^3. The sand is finer inside the lagoon. In the Thuan An inlet the sand has diameters of D_{50} = 0.39 mm, D_{90} = 0.81 mm (Lam 2009).

4. Thuan An inlet

This chapter concerns the general processes and mechanisms affecting the Tam Giang-Cau Hai lagoon system, its' inlets and the adjacent coastline. The chapter also focuses on the main problems regarding sedimentation related to the inlet and on the groin that has been constructed adjacent to the Thuan An inlet.

4.1. Identification of problems at Thuan An

Coastal erosion is a great and serious threat to people living in coastal areas, and it keeps on increasing. Erosion causes great and severe losses for the state as well as for the people (Hung 2012). One of the largest problems in the region of the Tam Giang-Cau Hai lagoon system and around Thuan An inlet is the erosion of the barrier islands and the infilling of the inlet. The erosion of the beach southeast of Thuan An inlet results in a movement of the inlet that cause problems for navigation, fishery, flooding discharge, and the ecological system inside the lagoon. In the area different fishing industries are of significant economic value, so the marine environment has a main role in the province's economic growth. A lot of money has earlier, before the building of the groin in 2008, been invested every year to dredge the access channel. The erosion of the shoreline also causes damage to the infrastructure and the beaches, which for example affects the tourism (Tung 2001). The main exchange of water between the lagoon system and the sea takes place through Thuan An inlet and when the inlet is narrowed due to sedimentation the quality of water in the lagoon deteriorates and it could ruin the aquatic ecosystem (Tushaj 2009).

If the barrier on the south side of the inlet will breach it will change the ecology of the lagoon through an alteration of the balance between saltwater and freshwater. The species living in the lagoon today cannot survive in a changed ecosystem and it will have a great impact on the fishing and aquaculture and in the long run on the people who make their living from these activities. A total siltation of the inlet is also impending and will cause problems for fishing activities, navigation of cargo and passenger ships heading for Thuan An harbour. Last but not least coastal protection is for the people living in the area, to protect their homes and livelihood (Tung 2001). The combination of a shallow lagoon with the migration as well as the siltation of the inlet decrease the evacuation capacity of a flood and increase the chance of an overflow. This can have severe consequences such as loss of human life, properties, livestock, crops, infrastructure and environmental pollution (Lam 2002). The sand barrier protects the coastal plains from a direct strike from a typhoon or extreme weather, but it also block flood waters coming from the rivers to flow out into the sea. The step hinterland in combination with large precipitation during the monsoons gives high peak discharges and floods the low-lying coast (Tung 2011).

If a coastal inlet closes there is a big risk of a breach in the barrier island at an unwanted location. The barrier island located between the ocean and the Tam Giang-

Cau Hai lagoon system inhabits a lot of people and a breakthrough threatens the safety of the people and the community (Tung 2011). In the big flood in November 1999, which also caused a breach at Hoa Duan, 324 people were killed or went missing, around 200 000 houses were flooded and damaged and 50 000 hectares of crops were destroyed, with a total economic loss around 112 million US dollars (Lam 2002).

To stop the erosion of the beach at Hoa Duan and to protect the banks at the inlet at Thuan An, and stabilize the navigation channel, a groin was built on the barrier island southeast of the inlet in 2008. There was also a system of breakwaters built on the northwest side of the inlet. The breakwater system northwest of the inlet functions as intended and the northwest bank is in 2012 more or less stable (Hung et al. 2012). Figure 4:1 is a satellite image over the area taken in 2005, before the groin was built, and the sand spit located on the east side of the inlet is more to the north-west than its present location shown in Figure 4:2. Before the groin was built there were severe problems with sedimentation of the inlet and five years after the construction of the groin the main problem is that the eastern sand spit at the inlet is eroding due to lack of sediment transport from the south, because of the groin. The sediment accumulates on the southeast side of the groin. Figure 4:2 also shows the breakwater system built on the northwest side of the inlet.

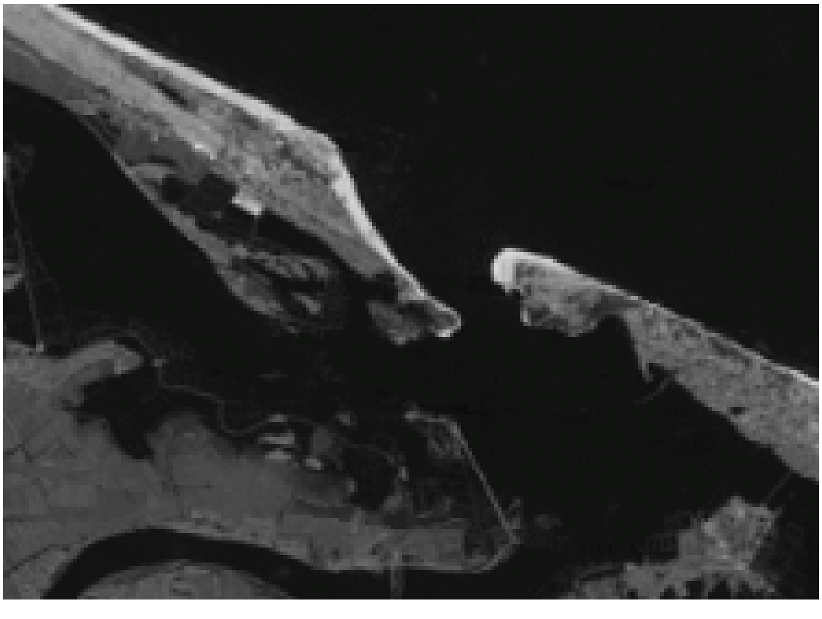

Figure 4:1 Satellite image over Thuan An inlet, 2005-03-09 Landsat image (Courtesy Dien D.C.)

Figure 4:2 Satellite image over Thuan An inlet, 2012-08-26 (Google Earth Image)

4.2. General processes

The morphological change of the inlet is a result of interacting geological, meteorological, hydrological, topographical and oceanographic factors. The dominating marine process is wave action and the river flow is the most dominating fluvial one. The tide in this area is too small (see chapter 4.2.1) to have a notable effect on the morphology. The eroding of the beach southeast of the inlet is mainly caused by that the magnitude of the net longshore sediment transport in northwest direction is large (Tung 2001). Sediment is mainly transported by rivers that drain into the lagoon system or alongshore the coastline by waves and by wind (Inman & Harris 1966).

The Thuan An inlet has a very different morphodynamic from Tu Hien inlet, both inlets being unstable but Thuan An inlet being the major inlet with the flow from Huong River and large erosion and sedimentation problems. Before the groin was built the inlet was threatened from the southeast by the sand barrier at Thai Duong Ha, which has caused the inlet to move in a northern direction and has also bent the flow of the Huong River into the inlet. South of the inlet the coastline eroded and the sediment was deposited in the inlet and developed shoals. Measurements done from 1999 to 2003 shows large sand erosions on beaches both north and south of the inlet and that sediment deposition took place on the south bank in the inlet (Hung 2012).

The two monsoon seasons have a great influence over the morphological behaviour of the Thuan An inlet and its' surroundings. During the northeast monsoon (September to December) the processes are fast and include inner channel reorientation, breaching of sand barriers due to river floods and inlet closure due to extreme typhoons. During the rest of the year the flow in the rivers is low and the wave action is dominant, and then the slow processes like accretion of inlet channels, migration of offshore bars and erosion/accretion of the adjacent shoreline (Lam 2009).

4.2.1. Waves and water levels

The tide outside Thuan An inlet is fully semi-diurnal with an amplitude of 0.3-0.5 m, which is the lowest tide along the coast of Vietnam. The tidal currents have a speed of 0.5-0.7 m/s at flood tide and 1-2 m/s at ebb tide and propagate from south to north (Tung 2001). The mean wave height is about 1 m and gives the coast the classification of a micro-tidal wave-dominated coast, as shown in Figure 4:3. This means that the waves have the main impact and the tide does not influence the morphology significantly, which leads to that the morphology is very dynamic and that the plan location and cross-section is frequently changing (Lam 2009).

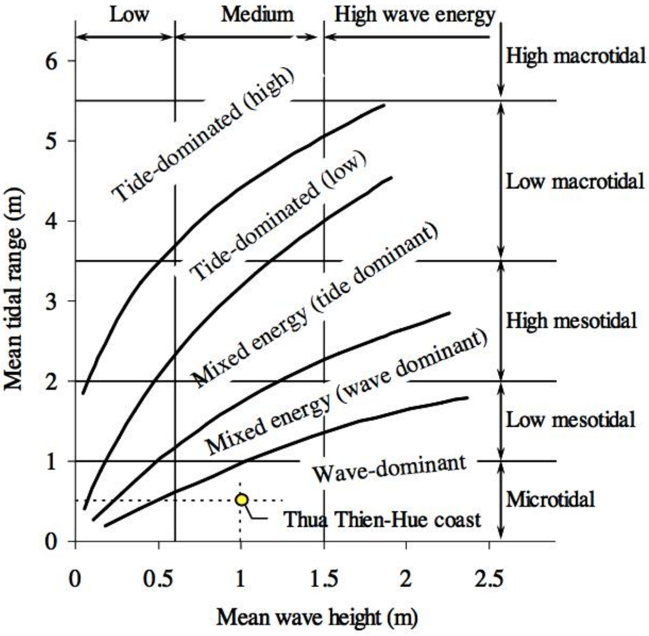

Figure 4:3 Hydrodynamic classification of the coast outside Thuan An inlet (Lam 2009).

Along the coast of Vietnam there are twelve marine hydrometeorological stations (HMS) that record wave parameters such as wave heights, periods and wind velocities. Near Thuan An inlet there are two stations situated; at Con Co Island and a deep sea station in the open sea outside Thuan An inlet (Hung 2012).

The coastline in the Thua Thien-Hue province and the surrounding provinces has a main direction of northwest to southeast, which makes the northeast monsoon winds perpendicular to the coastline. During the northeast monsoon and storm season the waves in this area are pretty severe. The main dangerous wave directions are north, northeast and east with an annual maximum wave height of 5.0-5.5 m. During the southwest monsoon the main dangerous wave direction is southeast with an annual maximum wave height of 3.5-4.0 m. Winds blowing from southwest will create a calm situation, due to that the wind blows from land to offshore. During monsoons the average wave height is 1.5-2.0 m and the average wave period is 5-7 s. The area also has the highest typhoon frequency in Vietnam with one storm per year, often occurring during September and October (Hung 2012). Figure 5:6 and Figure 5:7 show wave data roses illustrating the wave climate during the northwest respectively the southeast monsoon.

4.2.2. Hydrographic conditions

The Tam Giang-Cau Hai lagoon system is affected by both oceanic and inland conditions. The hydrological pattern of the rivers has a great impact on the inlets of the lagoon and this pattern is influenced by the rainfall pattern caused by the topography of the lagoon and the monsoon cycle. During the dry period the ocean mainly influences the lagoon and during the rainy period the floods from the rivers mainly influence it. Tropical cyclones or typhoons, cold fronts, tropical depressions or interactions between monsoons most often cause the floods (Lam 2009). The dry season last for eight months and during these months the flow in the rivers are small, which gives that the waves are dominant and transport a large amount of sediment into the inlet. During the rainy season the inlet morphology is even more dynamic and can change noticeably because of flood flow from the rivers (Nghiem et al. 2006). From June to November this part of Vietnam is regularly hit by typhoons and tropical depression storms and from September to December severe rainfall occurs due to the northeast monsoon (Tung 2011).

4.2.3. River flow and transport

The total sediment load that is transported to the lagoon by the rivers is circa 1.0-1.7 million m^3/year and it is estimated that the Huong and Bo rivers deliver approximately 80 % of this amount (Lam 2009). About 35 000 m^3/year of the sediment settles in growing deposits around the Thuan An inlet, mostly on the northern beach from Hai Duong to Thuan An (Tung 2001).

The O Lau, Bo and Huong rivers have a drainage basin of 3 600 km^2 and during February through August the river discharge is low due to limited rainfall. The wind transports beach sand inland to form dunes on the barriers and it is estimated that the wind helps adding to the barrier sand volume northwest of Thuan An inlet (Inman & Harris 1966).

The mean monthly inflow from the rivers into the lagoon is shown in Figure 4:4, depending on the hydrographical conditions that were stated earlier.

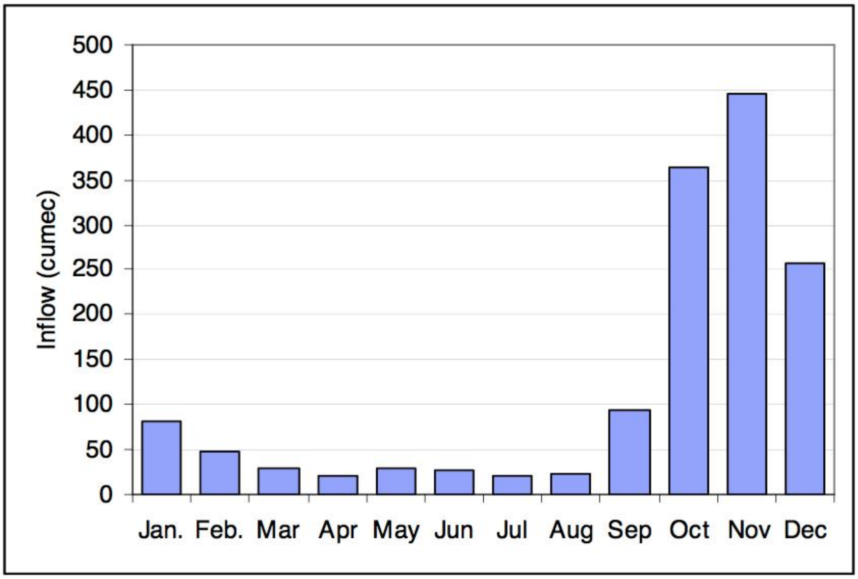

Figure 4:4 Distribution of mean monthly river inflow, cumec – cubic metre per second (Lam 2009)

When the river discharge is high there can be as much as a 2 m difference in water level on the two sides of Thuan An inlet, which generates a very high flow velocity in the inlet and this leads to changes to the morphology of the inlet. How the inner channel of the inlet will reorient depends on from which the direction the dominant flood flow is coming from. A larger flow from O Lau and Bo rivers, which gives that the flow from the north is stronger, the inlet channel will develop perpendicular to the shoreline with a direction to the northeast, see Figure 4:5 (Lam 2009).

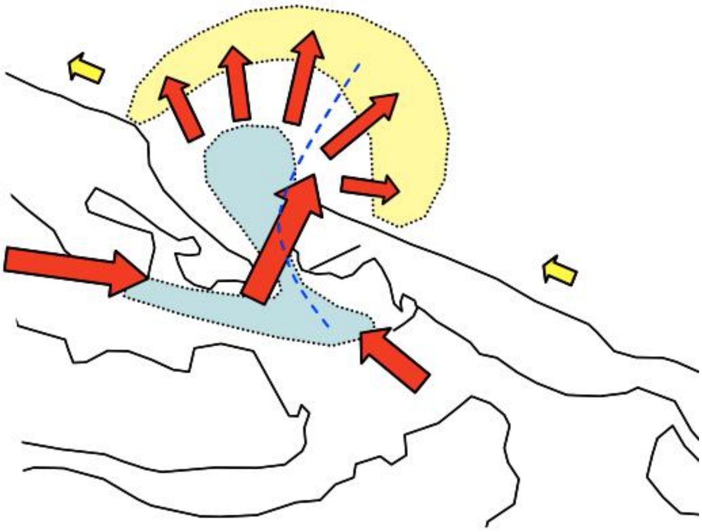

Figure 4:5 Domination of river flow from the north that causes the inlet channel to orient to the northeast (Lam 2009)

When the Huong River flow is dominant the course comes from the south and the inner inlet channel will turn to the northwest, see Figure 4:6. During the river floods the longshore sediment transport is interrupted, and the ebb-tidal delta and the inlet channel are eroded (Lam 2009).

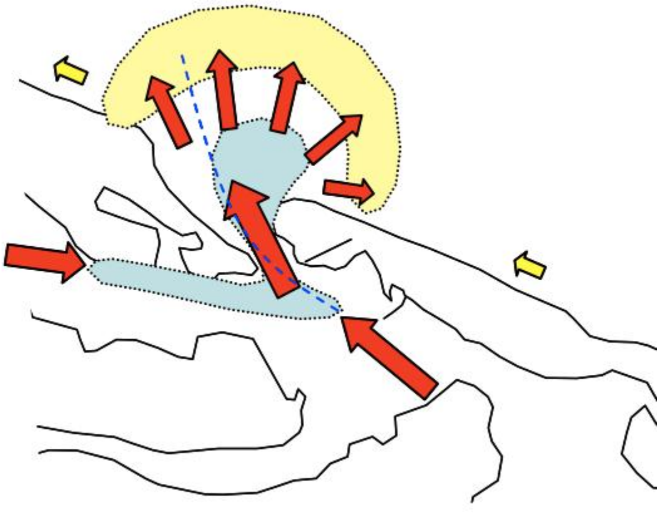

Figure 4:6 Domination of river flow from the south that causes the inlet channel to orient to the northwest (Lam 2009)

4.2.4. Sediment transport and morphological change

The coastline around the Thuan An inlet changes with the seasonally changing wave climate. During the southwest monsoon the beach profiles are mainly accreting and during the first part of the northeast monsoon they are mainly eroding. In the later part of the northeast monsoon (from November to March) the north-eastern winds are weaker than usual, leading to that waves build up sediment. Though some monsoon surges due to strong winds occur as well, causing coastal erosion. During this period the accretion/erosion process is complex, depending on the different beach profiles (Lam 2009). The coastline has a northwest to southeast direction so the northeast monsoon has a big effect on the longshore sediment transport. The waves in the area around Thuan An inlet is usually of high energy and with a large part of the wave direction perpendicular to the coastline the coastal bars become well developed (Hung 2012).

Lam (2002) presents calculations, done in 1999 by Vietnam Institute for Water Resources Research (VIWRR), that show a longshore sediment transport at Thuan An and Hoa Duan that is 1 503 000 m^3/year to the northwest and 63 000 m^3/year to the southeast. The net sediment transport is 1 440 000 m^3/year to the northwest and the gross sediment transport is 1 566 000 m^3/year. At Tu Hien inlet a gross sediment transport of 1 200 000 m^3/year is presented as plausible, computed by Haiphong Institute of Oceanography.

Lam (2009) evaluates different measurements and calculations regarding the longshore sediment transport done by different authors through the years of 1970-2004. The most reliable results (with an agreement to sand spit development in the inlet) is found to be in the range of 600 000-1 600 000 m^3/year in total gross transport and 300 000-700 000 m^3/year in net transport in a northwest direction. Calculations done by the author with the Bijker sediment transport formula gives a gross longshore sediment transport of 650 000 m^3/year and a net longshore transport of 250 000-360 000 m^3/year in a northwest direction.

Simulations done in 2001 shows in which directions the longshore sediment transport takes place in the area, see Figure 4:7. From Thuan An inlet and south along the coast until Thai Duong commune the sediment transport has a northwest direction and the simulation shows that the coastline had an accretion rate of 12 m/yr. From Thai Doung Ha commune down to Hoa Duan the longshore sediment transport has a northwest direction as well, but eroded with a rate of 8-10 m/yr. From Phu Thuan and south along the coast to Tu Hien inlet the longshore sediment transport has a southeast direction with a shoreline that is mostly stable and the Tu Hien inlet is silted by sediment transported from the north. The conclusion done by the author is however that the erosion and accretion rates in reality are lower than the simulated rates, but the direction of the sediment transport reflects reality (Tung 2001).

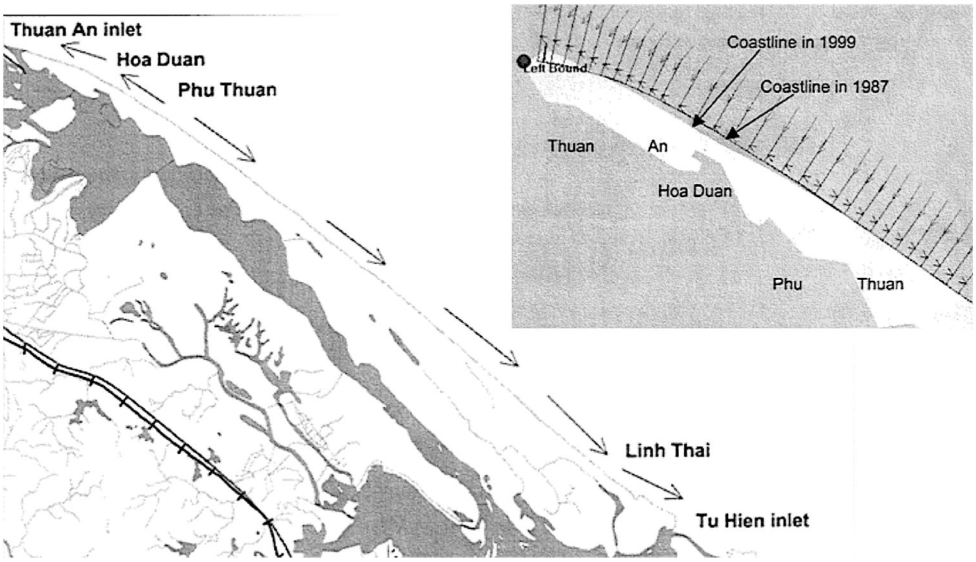

Figure 4:7 Sediment transport around Thuan An inlet (Tung 2001 - modified)

The seasonal variation between the river flow and the wave action being the dominating force gives seasonally alternating sediment transport pattern. The sediment that has been transported by the river flow out to the ebb delta is slowly modified by the waves, which approach the coast heading in a southwest direction. The transport of sediment along the coastline is abruptly broken of and the inlet is slowly filled up with sand. This gives that the coast on the down drift (southeast side) of the inlet will erode and the inlet will accrete, see Figure 4:8 (Lam 2009).

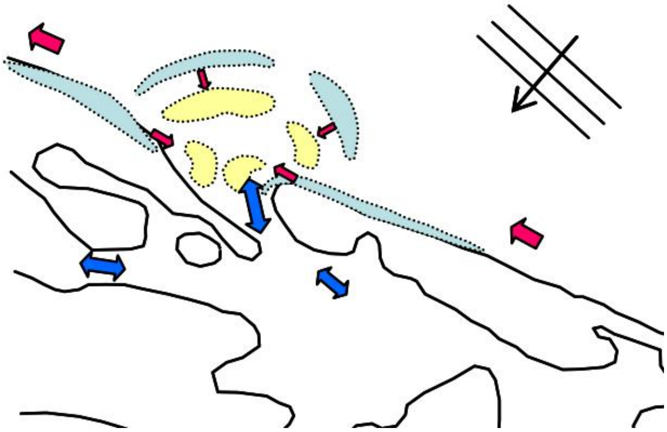

Figure 4:8 Fill up of the inlet channel, migration of sand bars and coastal erosion. Erosion takes place in the blue areas and accretion in the yellow areas (Lam 2009)

During the summer the waves are smaller and move sediment onshore, which restores the adjacent beaches of the inlet, see Figure 4:9. The ebb tidal deltas are reworked by the waves, the sediment that was transported to the delta is pushed back by the waves to fill up the channels and build up the shoals (Lam 2009).

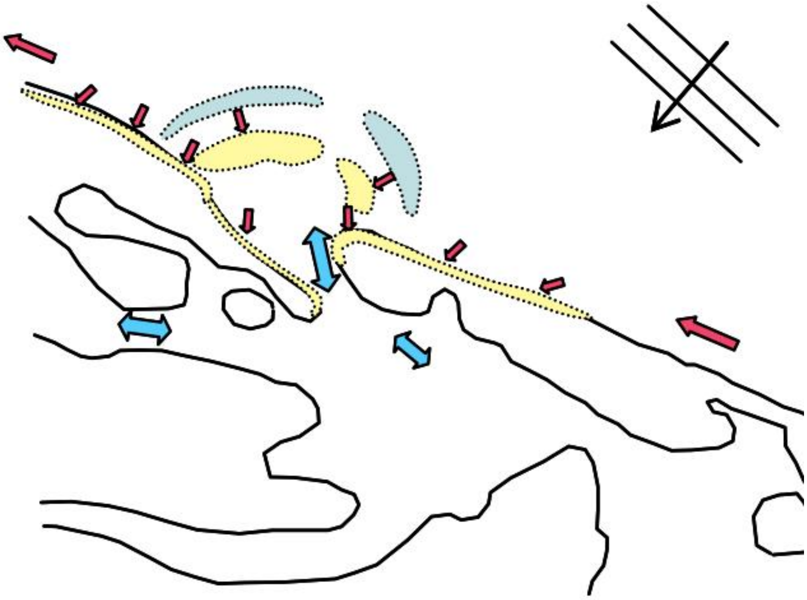

Figure 4:9 Recoveries of adjacent beaches. Erosion takes place in the blue areas and accretion in the yellow areas (Lam 2009)

The two monsoons also influence the sediment transport and the evolution of the inlet at Thuan An. During the northeast monsoon the flood season occurs that causes severe floods in the rivers due to high precipitation. The high river discharge makes the inlet channel scour and reorient, and the sand barrier islands may breach. An extreme typhoon can cause the inlet to close up. The rough sea causes the coast near the inlet to erode and the sediment is transported to the inlet where it accretes (Lam 2009). Figure 4:10 shows the main processes taking place during the winter monsoon.

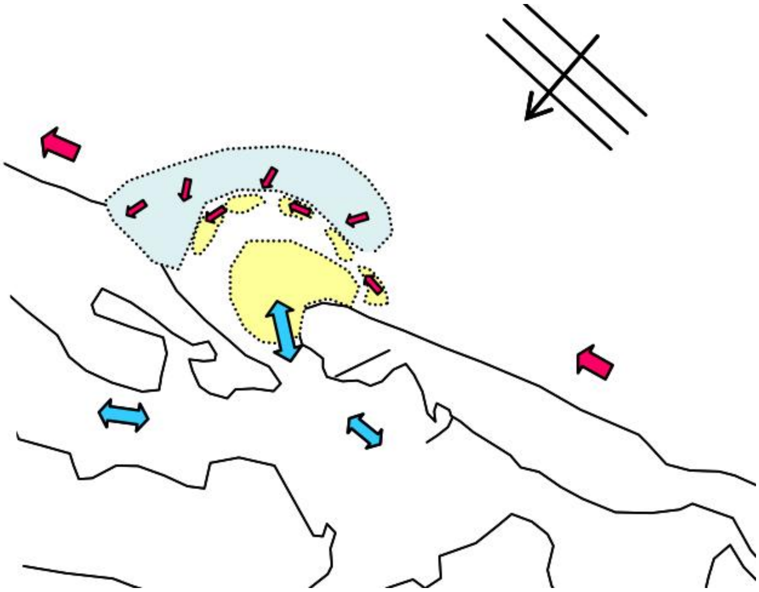

Figure 4:10 Erosion and accretion during the winter monsoon. Erosion takes place in the blue area and accretion in the yellow areas (Lam 2009)

The summer monsoon is dominated by waves from the southeast and there is no high precipitation that creates large floods in the rivers. The longshore sediment transport is in a northwest direction, which gives that Thuan An inlet becomes unstable and shoals are developed while sand spits are migrating. This gives that the inlet migrates to the northwest, see Figure 4:11 (Lam 2009).

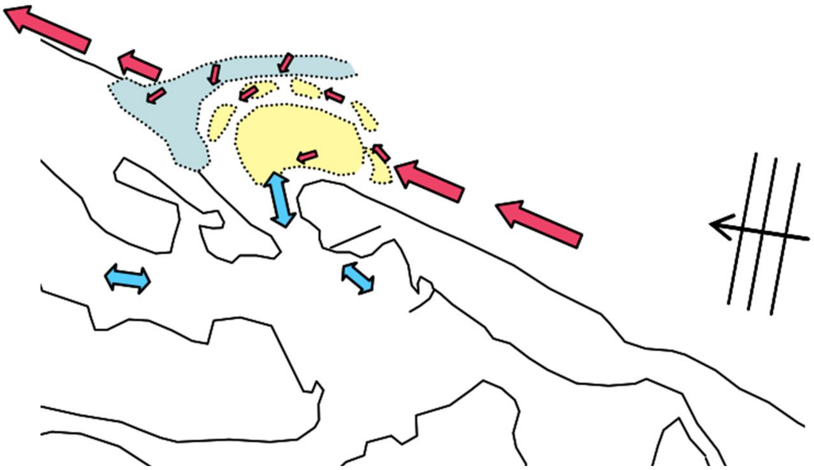

Figure 4:11 Erosion and accretion during the summer monsoon. Erosion takes place in the blue area and accretion in the yellow areas (Lam 2009)

4.3. Inlet evolution

In 2001 Thuan An inlet was 350 m wide, had an average depth of 5-6 m and was oriented in a NNW-SSE direction. In the dry season (February to August) the water velocity in the inlet is 1 m/s and during the rain season (September to January) it could get as high as 4-5 m/s (Tung 2001). The morphology of the inlets along the coast in the province is controlled by ocean waves, tides, river flows and topography of the continental shelf. The tidal range and current at Thuan An inlet are small and that gives that the wave actions and river flow have the largest influence over the morphology of the inlet. During the flood season the flow from the rivers is the dominant force, and when the flood season ends the wave climate gets dominating and has a strong influence over both the sediment transport as well as the morphology of the inlet (Lam 2009).

The inlet at Thuan An have a morphodynamic that is characterised by a potentially seasonal closure and the tropical monsoon climate conditions in the area influence the evolution of the inlet. Classification of the stability of the inlet gives that P/M_{tot} = 30, the ratio between the tidal prism and the total littoral drift. This shows that stability is “fair to poor” with shoals at the entrance and inlet migration. Studies show that the river floods and the high velocity flow jets that are created in connection with these floods mainly maintain the inlet. The longshore sediment transport in the area is also affected by the changes in tide in the ocean (Nghiem et al. 2006).

Lam (2002) models the stability of the inlet at Thuan An that shows that the stability is “fair to poor” (classification by the relation P/M_{tot}) and that the shoals at the entrance to the inlet cause difficulties for boats to navigate and for flood evacuation. The simulations also shows that if the inlet at Hoa Duan is opened, the stability of the inlet at Thuan An will become “poor”, which means that the flow in the inlet will not be able to keep the inlet open. Flow discharge and velocity at Tu Hien inlet is not effected by the opening of the inlets at Thuan An or Hoa Duan. The micro-tidal regime of the area gives that main sediment transport is wave induced and the sediment flushing done by the freshwater flow from the rivers are important to maintain the inlet.

4.4. Shoreline change

The stretch of the coastline in the area that was affected by the erosion (before the groin was built) is 2.5 kilometres long and begins north of Thuan An inlet, in Thai Duong Ha commune, and ends south of the (at the present closed) inlet in Hoa Duan commune. In the end of the 1990´s the beach eroded 15-20 metres during the northeast monsoon and accreted around 10 metres during the southwest monsoon (Tung 2001). The location of the shoreline in 1987 and 1999 is shown in Figure 4:12. The shoreline between Thai Duong Ha and Hoa Duan has eroded and the sand spit east of Thuan An inlet has accreted.

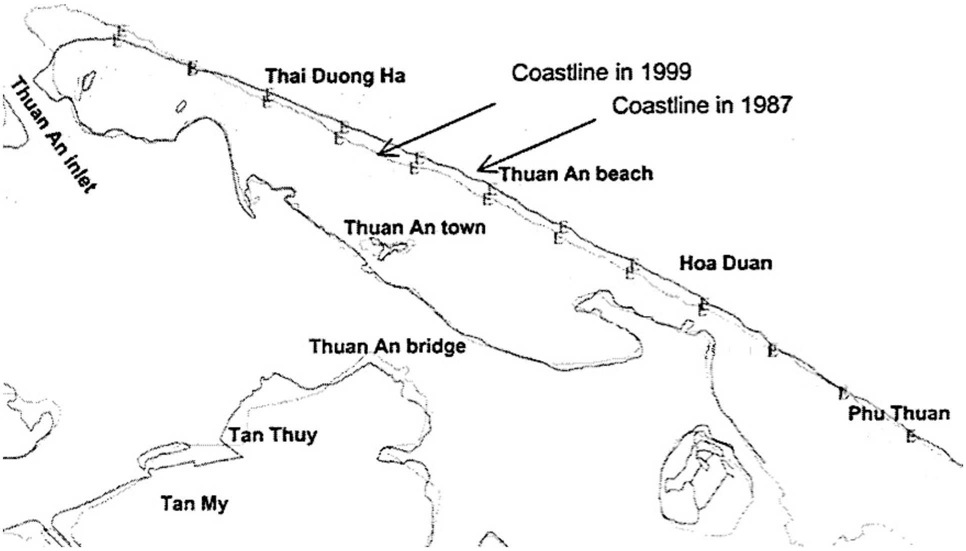

Figure 4:12 Orientation of the coastline south of Thuan An inlet in 1987 and 1999 (Tung 2001 - modified)

Measurements done by IMS in January 2007 and April 2008, just before the groin was built, are seen in Figure 4:13.

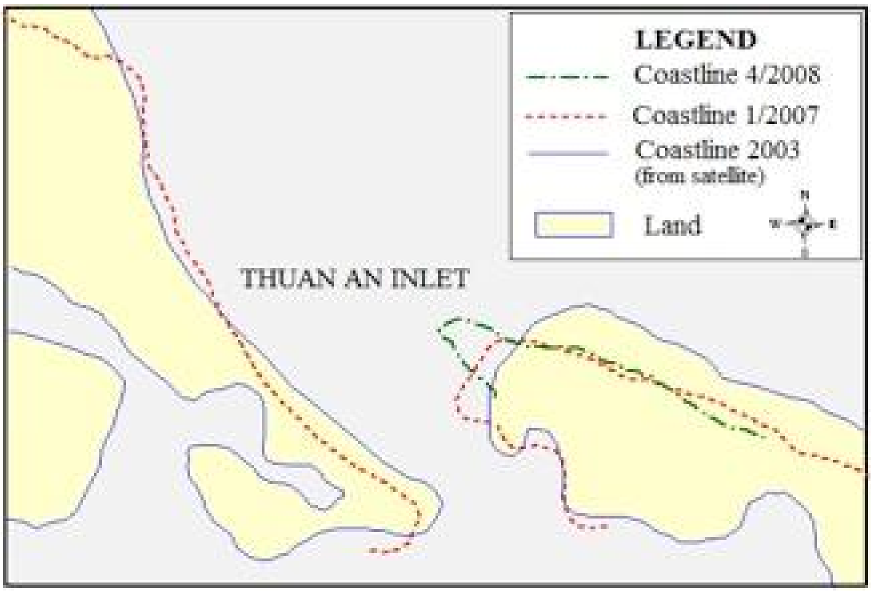

Figure 4:13 The shoreline at Thuan An inlet, measured before the groin was built (Hung et al. 2012)

4.5. Coastal engineering measures

When taking the decision to protect the beach from erosion and to form a hard solution, an investigation regarding what type of structure to build and analyses of physical processes in the area (like waves, nearshore currents and sediment transport) as well as the impact on adjacent beaches and the economical aspect should be made (Tung 2001). Unfortunately, for the groin built at Thuan An inlet in 2008 there has not been any available documentation on anything regarding planning, financing, building or maintenance, at least not anything that the authors could come across. Inman & Harris (1966) suggested in an early report how the inlet at Thuan An should be stabilized with an jetty and kept navigable trough dredging of the channel. Tung (2001) and Lam (2002) presents some more recent suggestions on structures and other measures, listed below, to solve the erosion and siltation problems at Thuan An.

Tung (2001) analyse the alternative of retreat and relocate against some different soft and hard measures. The suggestion to retreat and relocate is found to be an inoperable action because of the continuing erosion will damage the tourist beach and constructions like buildings, roads, electricity lines etc. There is also a possibility that there will be a breach of the spit, which will change the ecology of the lagoon, or if the inlet will close up due to siltation it will hinder the boat traffic. The thesis also investigate different engineering measures and draws the conclusion that two long jetties, one on each side of the inlet, together with beach nourishment is the best alternative at Thuan An inlet, but also the most expensive of the alternatives looked into. Just to do a beach nourishment will re-establish the beach for a shorter period, but the longshore sediment transport will continue and the nourishment will have to be repeated. Just to build one long groin is not considered to be a good protective measure because of the downstream erosion that it creates and the sediment deposition in the whirlpool on the lee side. The construction of a groin field at Thuan An beach will reduce the longshore sediment transport, it is cheaper than the other alternatives but the negative effect is that the beach erosion problem will move to adjacent beaches.

Lam (2002) models the stability of the inlet with regards to sea water level, inlet openings and river flow. A calculated cross section with a width at 500 m and a depth at 10-11 m will give a maximum mean flow velocity of 1 m/s, which keeps the sediment in the inlet from shoaling. The stability of the inlet is suggested to be kept fixed with jetties and the inlet at Hoa Duan must be kept closed. At high river flood discharges the risk of overtopping sand barriers and create a breakthrough exist and to enhance the capacity a dam structure is suggested to be built.

In April 2008 a groin was constructed on the south-eastern side of the Thuan An inlet, as an attempt to prevent sedimentation in the inlet and to stabilise it. Another main function was also to protect valuable tourist beaches from erosion. At the same time, a breakwater system was also built on the north-western side of the inlet to protect the adjacent village and (Hung et al. 2012). The constructions are shown in Figure 4:14.

The groin has a length of 325 m and it is almost perpendicular to the shoreline, an angle of 31.36 degrees with regards to the true north (Dien 2013). The theory regarding groins gives that the length of the protected coastline will be five times the length of the groin. The groin at Thuan An inlet will protect approximately 1,6 km of the beach, which is not enough to reach and protect the tourism beach at Hoa Duan (Hung et al. 2012).

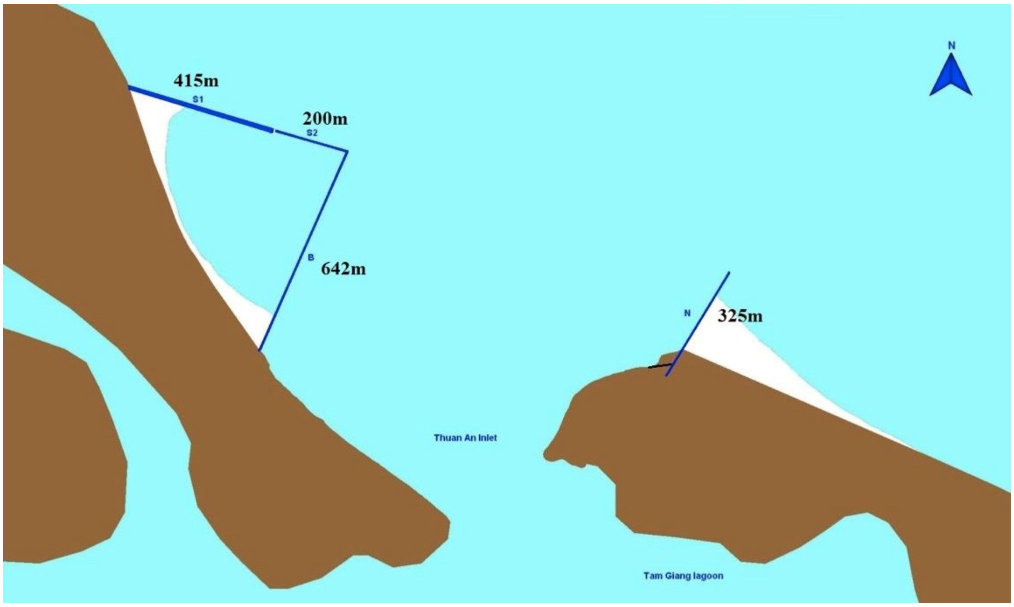

Figure 4:14 Drawing of the breakwater and the groin at Thuan An inlet, made in 2011 (Dien 2013)

The breakwater on the north bank of the inlet is today more or less functioning (see Figure 4:15) and the coastline is relatively stable, while the coastline in the south bank where the groin is situated is changing significantly (see Figure 4:16). The groin stops the sediment transport along the coast in a northwest direction and sediment accumulate on the south side of the groin. On the north side, at Thuan An inlet, severe erosion is taking place due to the loss of sediment transport to the inlet. The effect of the groin is reinforced by the current patterns in the inlet, caused by the flow from the rivers that spill out in the lagoon. At the time when the article was written there were no plans for taking any interventions to improve the functionality of the groin (Hung et al. 2012).

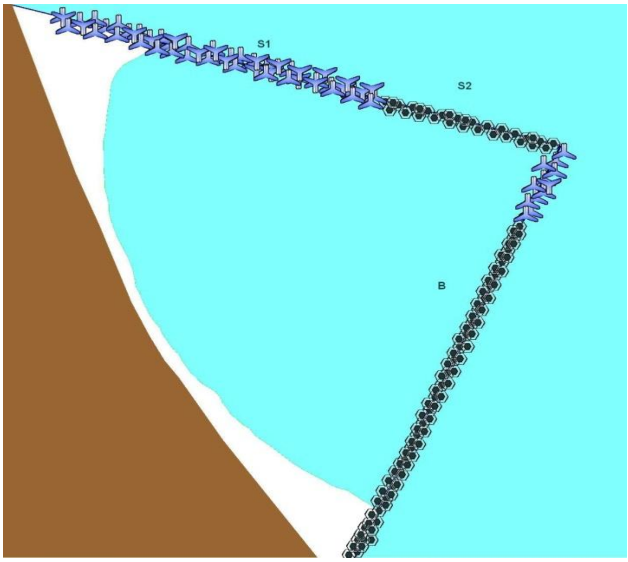

Figure 4:15 Breakwater built north of Thuan An inlet, pictured in 2011 (Dien 2013)

Hung et al. (2012) calculates the efficiency of the groin with an estimated capturing capacity of 50 % and a net sediment transport rate of 400 000 m^3/year. The average annual seaward advance of the shoreline at the groin is calculated to be 80 m/year, which in 2011 coincides with the total accretion distance that was 240 m since the groin was built three years earlier. The authors expresses that since the rather short length of the groin it does not play a significant role to the stabilization of the Thuan An inlet, although it affects the inlet indirectly by stabilizing the shoreline south of the inlet that due to erosion earlier could change significantly over a year and by removal of the shoaling area at the seaside inlet entrance. On the downdrift side of the groin the erosion is growing to be severe and the approaching sea threatens constructions along the shoreline. The article advises that the function of the groin will be done by 2015, this is because that the gradual accretion on the updrift side will increase the amount of sediment that bypass the groin head.

Figure 4:16 Groin built south of Thuan An inlet, pictured in 2011 (left) and 2012-08-26 (right) (Dien 2013, Google Earth Image)

Figure 4:17 shows the appearance of the groin, depicted at the field study that was carried out in the middle of January 2013.

Figure 4:17 Groin at Thuan An inlet, January 2013 (Photo: Eva-Lena Eriksson)

5. Field measurements and data analysis

This chapter considers the field measurements, how they were executed and what kind of data that was obtained from the measurements. Available data concerning the Thuan An inlet and the adjacent groin, both data obtained from the field measurements and data that has been collected previous years, are being compiled and analysed.

5.1. Overview

The required data to create the model used in this study is wave data, information regarding the groin, position of the shoreline, characteristics of the beach and the beach profile. The position of the shoreline was measured during the field study in January 2013 and the additional data was obtained from the Institute of Mechanics in Hanoi.

5.2. Experimental setup and procedure

5.2.1. Field measurements

The required field measurements were carried out outside of the Tam Giang-Cau Hai lagoon, outside of the city of Hue in central Vietnam, as the investigated groin is situated there. In order to study the effects on the erosion and sediment transport caused by the groin placed close to the Thuan An inlet, the shore line has been measured with a GPS during several years, to see how it changes due to the impact of the groin. The measurements have taken place between one to three times per year since 2007 and are continuously being performed every year by the Institute of Mechanics in Hanoi. Between the years 2008 and 2011 the survey was funded by the Vietnam – Sweden Project RDE-03. If extended funding were available more measurements, such as deep sea wave data, sediment transport in the surf zone, longshore currents etc., would also have been done more frequently.

The measurements were performed by walking with a GPS along the sea by the Thuan An inlet (as can be seen in Figure 5:1), which is the northernmost inlet to the Tam Giang-Cau Hai lagoon. The coastline on both sides of the groin were measured and the position of the first and last (2007 respectively 2013) measured shoreline is presented in Figure 5:2. When measuring two GPSs was used, to be able to validate that the measured data was correct, and the shoreline was defined by the berm crest. Since the tide in the area is so small it does not make any difference in when during the day the measurement is done.

Figure 5:1 Measuring the coastline during the field study, January 2013 (Photo: Madeleine Hjertstrand)

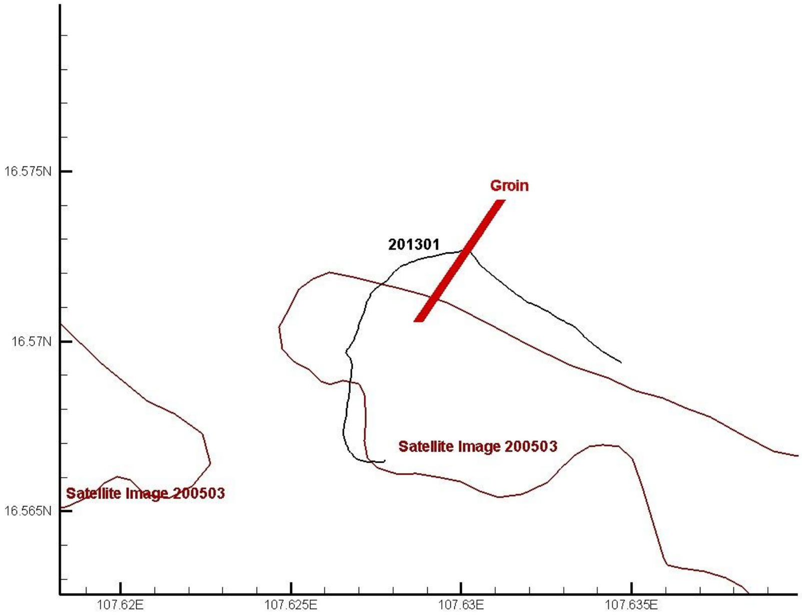

Figure 5:2 The shoreline of Thuan An inlet in January 2013 (blue) compared with March 2005 (brown) (Courtesy of Dien D.C.).

5.2.2. Previously collected data

During the field study made in January 2013 only data regarding the position of the shoreline was collected; other data have been collected earlier. The relevant data for this study that had been collected previously was obtained from the Institute of Mechanics in Hanoi. This data include wave data, bathymetry data, information on coastal structures and measurements of the shoreline positions performed since 2007.

5.3. Data collection and their properties

5.3.1. Wave data

The wave data has been calculated at two measuring stations outside Hue; Con Co that has the position 17.25N, 107.5E, located at a depth of 45 m, and HQ1 (deep sea station located in the open sea outside of Thuan An inlet**)** that has the position 16.5N, 108.0 E, located at a depth of 50 m, see Figure 5:3.

Figure 5:3 The two measuring stations Con Co and HQ1 outside of Hue (Google Earth image)

The wave data used in this study contain information about wave direction (degrees), wave height (meters) and wave period (seconds). In this study it is the data hindcasted at the Con Co station (calculated wave data based on measurements) that is used and it contains data values for every third hour during the years 1991 to 2012, compiled by the Hydrometeorological Observation Network of Vietnam

(Tung 2011). This hydrometeorological measuring station lies on the Con Co Island, which is located 75 km northwest of the Thuan An inlet and was built in 1965. At this station wind and wave data have been collected continuously since 1965 until today and therefore this data has the longest range and is the most reliable (Tung 2001). The wave climate measured at the Con Co station corresponds better to the sediment transport of the area in this study than the data measured at the HQ1 measuring station (conclusion after discussion with prof. Nguyen Manh Hung).

An evaluation regarding which measured wave climate that produces the most reliable longshore sediment transport rate is done in chapter 7.1.5.

5.3.2. Bathymetry data

The bathymetry data contains information about the topography of the sea bottom, i.e. the water depths. It is usually measured with the sonar method (**so**und **na**vigation **r**anging), which implies that a short high-frequency sound pulse is sent out, and the time it takes for the sound to travel to the sea bottom and be reflected back is measured (Water Encyclopedia 2013). The bathymetry data used in this model was obtained from Institute of Mechanics in Hanoi.

The bathymetry data is translated into the model, created in GENESIS, through the measured appearance of the beach profile. The elevation of the berm and the seaward limiting depth, measured from a vertical datum e.g. mean sea level, are used in the model.

5.3.3. Shorelines and inlet evolution

Data regarding the position of the coastline has been collected during the years 2007 and 2013 and the changing coastline over these years is presented in Figure 5:4. The coastline measured in January 2013 is presented in Figure 5:2. As can be seen in the figure the development trend of the inlet is that it is getting larger and larger over time due to the erosion of the coastline on the northwest side of the groin.

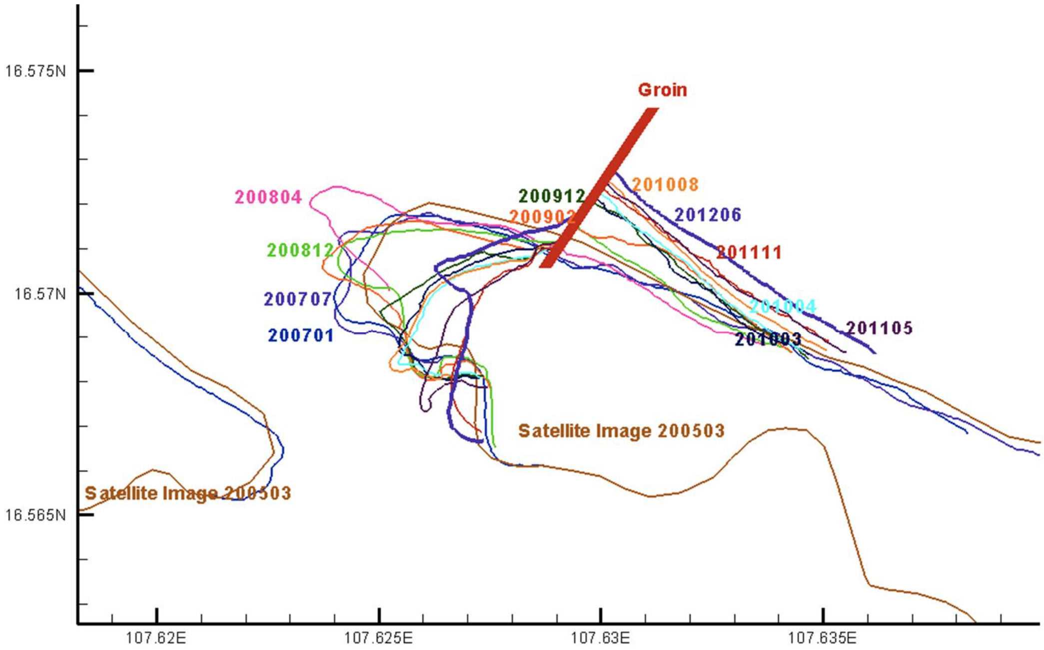

Figure 5:4 The changing of the coastline at Thuan An inlet during the years 2005 to 2012 (Courtesy of Dien D.C.). Longshore sediment transport and shoreline change

The longshore sediment transport is dependent on the wave climate, which can be presented as wave roses as can be seen below in Figure 5:5 to 5:7. These wave roses are based on wave data (from the Con Co station) from the years 1991 to 2011 calculated with the SWAN model.

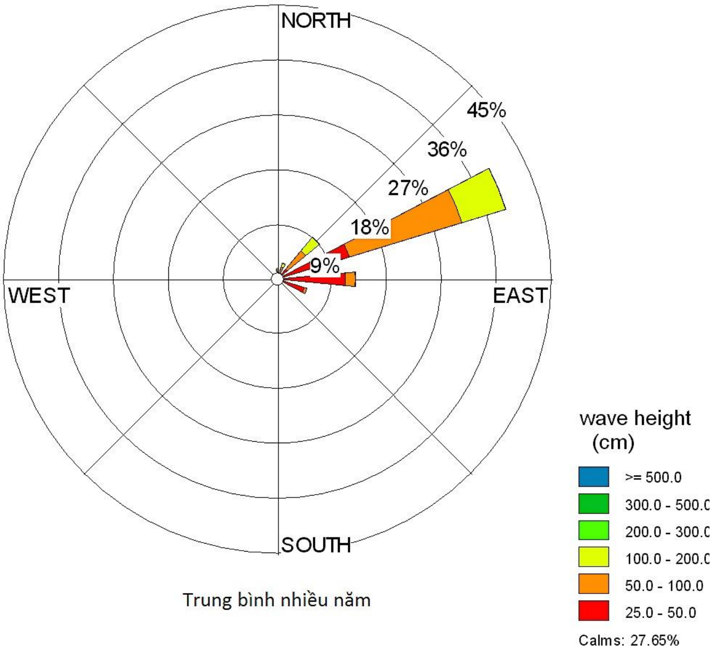

Figure 5:5 Wave rose describing the annual average wave direction and wave height during the years 1991-2011 (Courtesy of Dien D.C.)

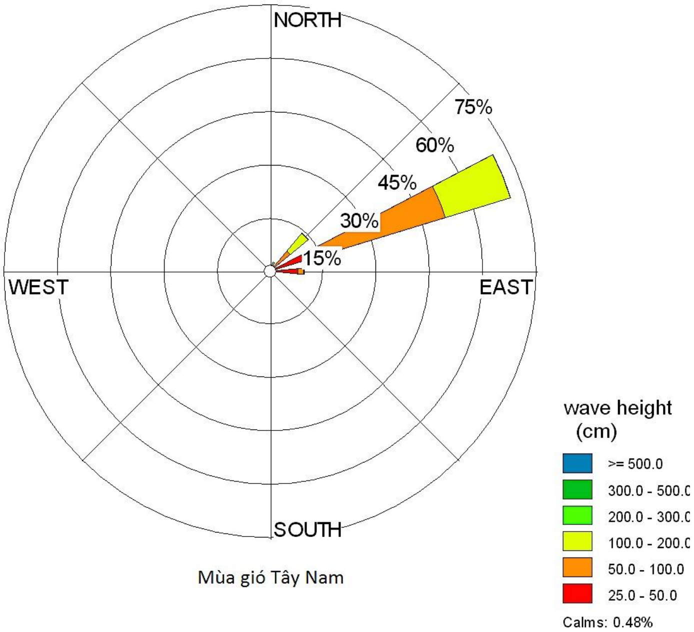

Figure 5:6 Wave rose describing the average wave direction and wave height during the northeast monsoon during the years 1991-2011 (Courtesy of Dien D.C.)

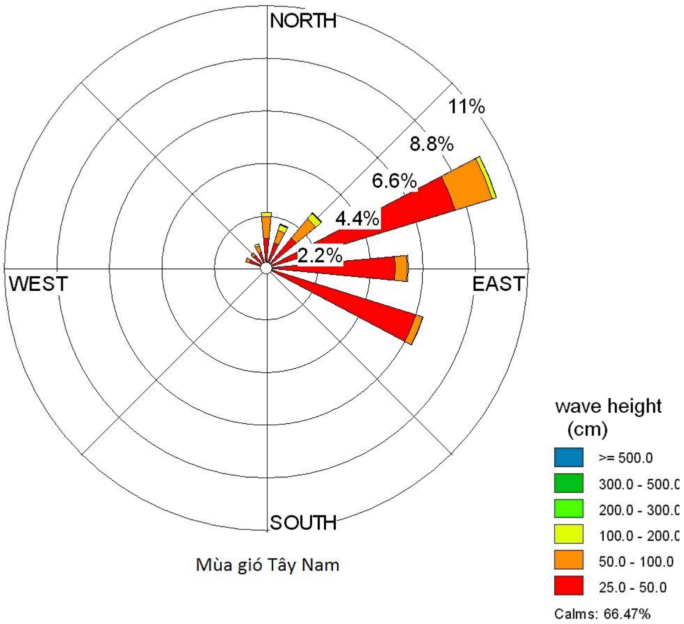

Figure 5:7 Wave rose describing the average wave direction and wave height during the southwest monsoon during the years 1991-2011 (Courtesy of Dien D.C.)

6. Model application to the groin at Thuan An inlet

In this chapter the application of a model simulate the shoreline evolution at the groin at Thuan An inlet is performed and the result is presented. The set up of the model, input data and calibration and validation of the model is presented. Different measures on how to reduce the erosion in the concerned area are simulated. The results from the modelling are discussed in chapter 7.

For creating the model and running simulations the programme GENESIS95 (version 3.0) was used. An example of an input START-file (for calibration period 200804-201004) is found in Appendix 1. A short presentation of the software modelling programme GENESIS and how it works is found in Appendix 2.

6.1. Setup and input data

6.1.1. Creating of the conceptual model

A Cartesian coordinate system was applied over the study area; with origin located in the lagoon inlet, the x-axis following the main trend of the coastline and the y-axis aligned with the groin, see Figure 6:1. The origin has the coordinates (lat 107.622, long 16.57) and the x-axis has its end point at (lat 107.638, long 16.5631). Only the coastline southeast of the groin is used for the simulations (according with the limitations presented in Chapter 1.4).

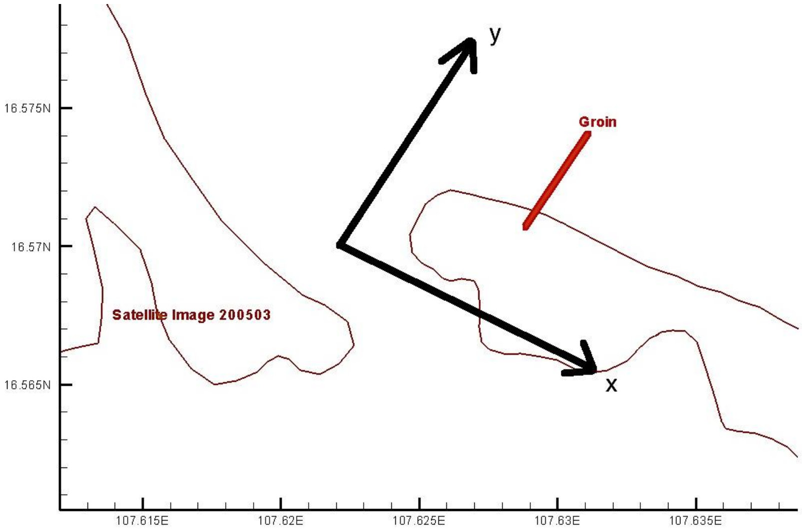

Figure 6:1 An approximate figure of the coordinate system applied to the study area at Thuan An, with origin located in the lagoon inlet (Courtesy Dien D.C. – modified).

The coordinates of the measured coastlines were specified in latitude/longitude and since the input of the shoreline data in GENESIS had to be with regard to the coordinate system, recalculation was made of the shoreline coordinates into the local coordinate system. The grid spacing dx along the coastline was set to 25 m and the total length of the calculation area became 2.5 km. The conditions at the boundaries of the grid are essential information for the simulation of the sediment transport rate in and out of the model area. The left boundary (to the northwest) was set to be the groin, i.e., a gated boundary condition, and the right boundary (to the southeast) was set to be a pinned-beach condition on the assumption that this boundary maintains a balanced sediment budget and does not accrete or erode.

6.1.2. Incoming wave data

The internal wave transformation model in GENESIS was used.

The angles of the incoming waves had to be recalculated, since they were measured from true north and in a local coordinate system. The y-axis in the model is perpendicular to the shoreline trend, i.e. parallel to the groin instead of true north. The angle between true north and the y-axis in the local grid, called *as*, was estimated to 22.5 degrees and the angle *aw* was defined as the incoming wave angle as measured from true north, see Figure 6:2. The wave angle according to the local coordinate system was calculated by taking the incoming wave angle (*aw*) minus 22.5 (*as*).

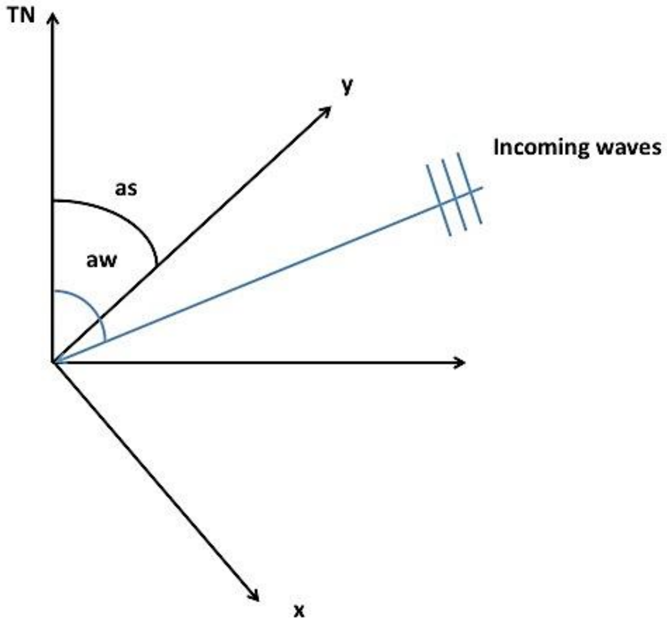

Figure 6:2 Definition sketch for wave angle conversion

The wave input data is entered into GENESIS through the WAVES file, which consist of three columns; the first one containing the wave period, the second the wave height and the third the wave angle. The input wave angle had to be specified with regards to how GENESIS reads wave data. An incoming wave that is perpendicular to the coastline is defined with the angle zero, if the wave arrives from the north-east it has an angle between 0 to -90 degrees and if the wave approaches from the north-west the angle is between 90 and 0 degrees, see Figure 6:3. This means that all measured wave angles with a value of 0-90 degrees were set as negative (0--90) and all angles from 270 to 360 degrees were recalculated by taking 360 minus the value of the angle (90-0). GENESIS disregards all waves that approach the shoreline with an angle between 90 to 270 (-90) degrees since they do not produce any longshore sediment transport.

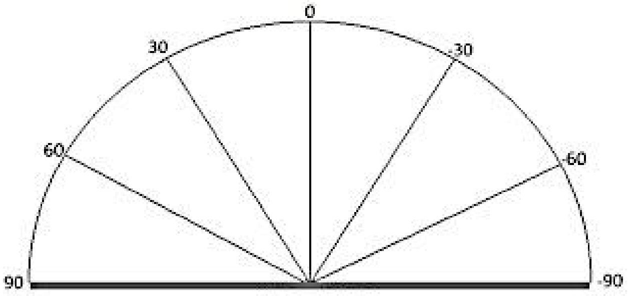

Figure 6:3 Definition of wave angel in GENESIS (Dien 2013)

6.1.3. Shoreline properties

A year before the groin was built and up to January 2013 the position of the shoreline at Thuan An inlet has been measured two to three times per year. The length of the measured coastline stretch varies from time to time and to get the same number of data points in the input data files, as the initial shoreline in April 2008, points had to be added in the end of the files. Both SHORL and SHORM files got data added and information regarding each lengthening is found in the chapters describing the calibration and validation. When setting up the model area it is preferred that the coastline stretch southeast of the groin is as long as possible. This is mainly due to the assumption that the right boundary is assumed to be a pinned-beach and that the groin in theory affects a coastline stretch of five times its length. As the initial shoreline the values measured in January 2007 was used, instead of the shoreline measured in April 2008 right after the groin was built. This is because a longer stretch of the shoreline was measured in 2007 than in 2008, which gives more data points for the simulation. The use of the shoreline measured in 2007 could be done since the two coastlines southeast of the groin are very much alike, see Figure 6:4.

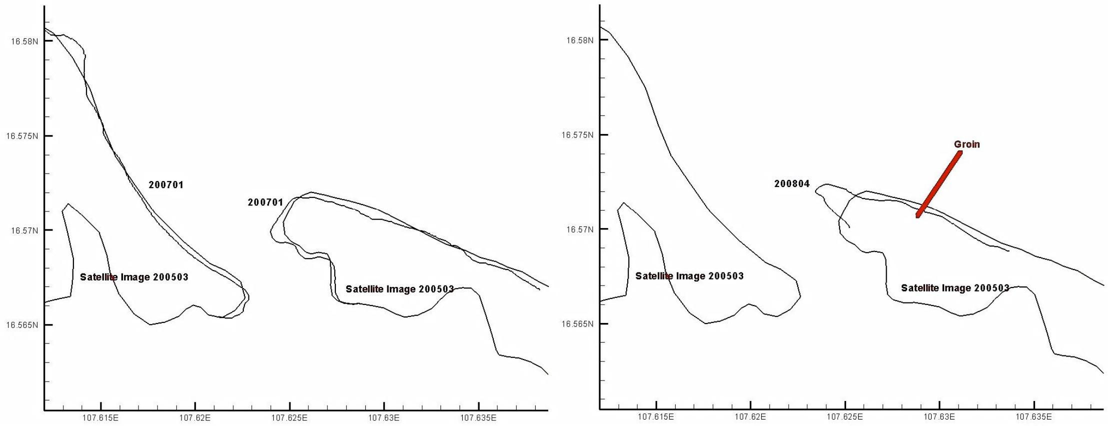

Figure 6:4 The location and length of the measured coastline in 2007-01 (left) and in 2008-04 (right) (Courtesy Dien D.C.)

The berm elevation D_B was set to 2 m and the closure depth D_C to 6 m. The closure depth was estimated from the value of 8-10 m that was discussed by Hung et al. (2012), applied to the whole beach stretch outside Thuan An. Also, when the calibration was performed a lower value on the closure depth D_C gave a more accurate appearance of the modelled coastline. The berm elevation was then estimated with regards to the closure depth and the topology of the beach surrounding the groin.

6.1.4. The groin

The initial length of the groin from the shoreline is 325 m and modelled as a non-diffracting groin. In the model the length of the groin is entered as the length from the x-axis, which gives a length entered in the START file of 700 m. In the plots of the results from the modelling in GENESIS the groin is, however, plotted with a length of 325 m and the position of the shorelines are adjusted in the same way. When the groin was newly constructed the permeability was set to be zero in the model, but the assumption was made that after a couple of years the groin start to let through some sand based on the fact that the surrounding beach has built up to have the same height as the groin, see Figure 6:5, and also the groin has deteriorated. The permeability during the two validation periods was therefor set to 0.1.

Figure 6:5 The groin at Thuan An inlet, photo taken from the end of the groin towards the shoreline. Picture of the beach and the groin at the same height, showing the groin to be permeable (Photo: Eva-Lena Eriksson).

6.1.5. Longshore sediment transport

The net and gross longshore sediment transport along the coastline was calculated by the Institute of Mechanics in Hanoi with the help of SEDTRAN, a sand transport-modelling programme. The wave data calculated at Con Co station during 1991-2012 was used and the calculation gave a gross transport of 1 400 000 m^3/year (820 000 m^3/year to the west and 600 000 m^3/year to the east) and a net transport of 220 000 m^3/year to the northwest. The gross and net sediment transport varies depending on the wave data that is used and on which transport equations that are applied to calculate the rate of the transport. The transport rate quantified in chapter 4.2.4 range between 600 000-1 600 000 m^3/year in gross transport and 300 000-700 000 m^3/year in net transport to the left along the shoreline. This demonstrates that the wave data calculated at Con Co results in a sediment transport that correlates with earlier studies both regarding rate and direction. Thus, these wave data were used at the modelling of the groin and gave a yearly net sediment transport to the left, leading to that sediment was built up on the southeast side of the groin as observed at Thuan An.

The wave data that correspond to the years when the shoreline position was measured was used in the model, i.e. the years 2008-2012. The two calibration parameters K_1 and K_2 was altered to get the correct rate of the transport, so that the calculated shoreline agreed with the measured ditto. The variable K_1 is a transport parameter that also controls the time scale of the shoreline response and for a sandy beach the value should be between $0.1 < K_1 < 1.0$. The parameter K_2 relates to K_1 through the expression $0.5K_1 < K_2 < 1.5K_1$.

The internal wave transformation model calculates where the incoming waves break, which is a function of the wave characteristics and the shoreline orientation. The value ISMOOTH, found in the input file, can be altered to change the appearance of the bottom contour. ISMOOTH is the number of calculation cells included in smoothing the shoreline to define the shape of a representative offshore contour. If ISMOOTH is set to 0 no smoothing is performed and the contour will follow the shoreline, but if instead N is entered the contour will be represented by a straight line parallel to a line drawn between the two end points of the shoreline. The default value 11 was used for the simulations. A lower value was tried to reduce the tweak on the calculated shoreline by the pinned beach, which can be seen in Figure 6:8 on the calculated shoreline presented in green. When running the model for different measures and using a lower value on ISMOOTH the simulation was cancelled before it could finish and to be able to run the model the value of ISMOOTH had to be set to 11. This gives that the tweak on some of the calculated shorelines remains by the pinned beach, but is disregarded from in the calibration of the model.

6.2. Calibration and validation

The simulation of the shoreline southeast of the groin is divided into three stages; calibration, validation and modelling of different measures to reduce the erosion of the inlet. The set-up of the model is done through calibration and validation, and to get the most accurate model data from the whole time period during which measurements of the shoreline at Thuan An were performed was used. The start of the model set up was in April 2008, when the groin was built, and ends in January 2013 as the last measurement of the shoreline was made. Because of the amount of data regarding the positions of the shoreline, which also has correlating wave data, the calibration as well as the validation was divided into two periods. The start of the model calibration period was set to April 2008 and ends in April 2011. It is divided into two calibration intervals; 200804-201004 and 201005-201104. During the two calibration periods the values of the different parameters in the START file is kept the same. The validation was done from May 2011 to January 2013, divided on to the two periods 201105-201206 and 201206-201301. The decision to divided the calibration and validation into two periods each was done because it was thought that it would be easier to perform the calibration when having more shoreline positions to compare with. By dividing the calibration and validation into two periods instead of one will not affect the result, it is only done to simplify the calibration of the model.

The first calibration interval is set to two years since the measured shoreline from the spring in 2009 is regarded from. This is because that the appearance of the shoreline near the groin on the southeast side is deviating from the other measured shorelines by not having the most sediment build next to the groin but instead some distance away from the groin, see Figure 6:6. The assumption was made that the measurement was carried out just after some deviating wave climate had struck the area and therefore is the position of the shoreline assumed to not represent the transport of sediment over a longer time period. Neither does anyone of the other measured shoreline positions show this deviating appearance.

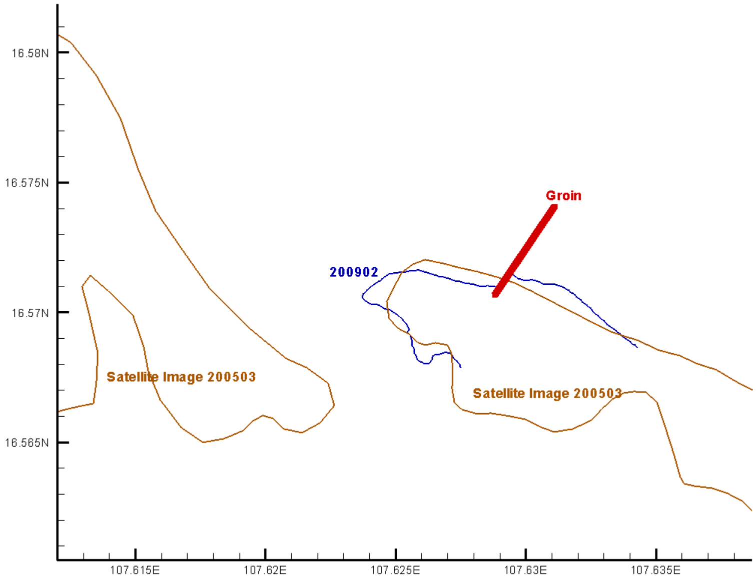

Figure 6:6 The shoreline at Thuan An, measured in February 2009 (Courtesy Dien D.C.).

Four START files were created for the periods of calibration and validation. Values regarding the coordinate system, bathymetry, simulation time, wave information, the beach and the groin are inputs found in the START files. The corresponding wave data is collected from the WAVE file by entering the correct simulation period in the START file.

GENESIS uses the data of the measured shoreline found in the SHORM file to calculate a calibration/verification error between the by GENESIS calculated position of the shoreline and the measured ditto. Since the SHORM file has been modified (as explained earlier) by adding coordinates in the end of the file to gain sufficient length of the shoreline for the modelling, the calculated calibration/verification error will not show the true error and this number is therefore not used when the calibration is carried out. The size of the error is not presented in this report, because it is irrelevant when a comparison cannot be made. The calibration can also be carried out by comparing the plot of the shoreline measured at the end of the period and the by GENESIS calculated position of the beach, which is the method used. The calibration was carried out by comparing the plots of the measured and calculated shoreline and by adjusting the calibration coefficients K_1 and K_2 until a satisfied correlation between the two shorelines was achieved. The length of the actual measured shoreline is specified for the periods of calibration and validation, to be able to know which part to use when doing the visual comparison and which part to disregard from. The coefficients was set to $K_1=0.11$ and $K_2=0.10$.

6.2.1. Model calibration

The coordinates of the initial shoreline in April 2008 were entered in the SHORL file, for the model to gain an initial value of the location of the beach. The shoreline coordinates measured in April 2010 were entered into the SHORM file, which is then used to calibrate the calculated shoreline. The length of the measured coastline stretch in April 2010 are the 24 first coordinates, which gives a beach length of 600 m, and the rest are copied from the April 2008 SHORL file. The calculated and calibrated position of the shoreline in April 2010 is plotted in Figure 6:7 together with the measured shorelines of April 2008 and April 2010.

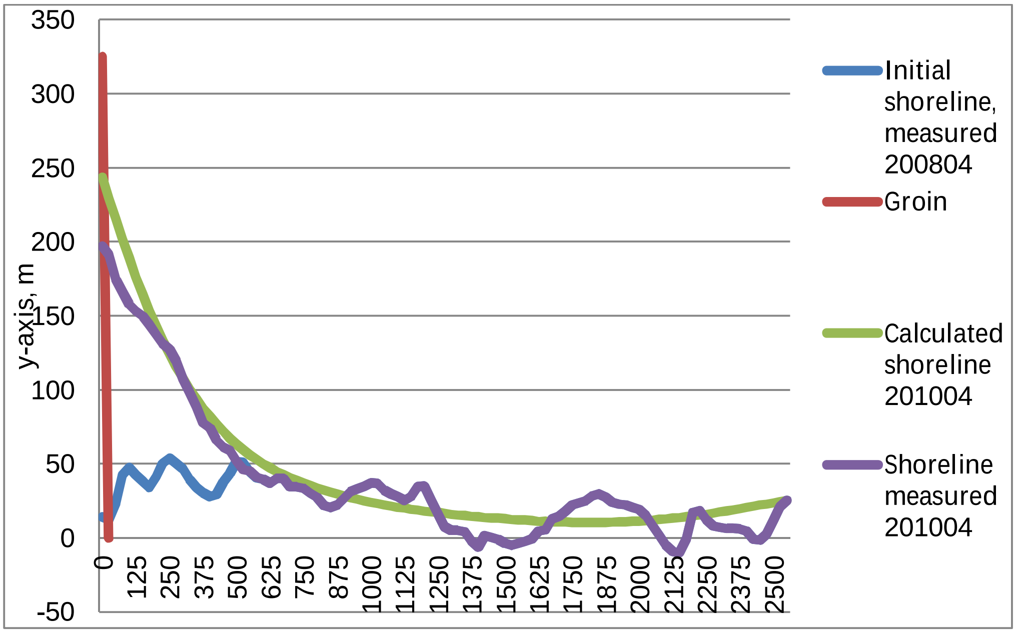

Figure 6:7 Model calibration during the period 20080401-20100430. The output from the GENESIS calculation is plotted in green.

For the second calibration period the previous calculated shoreline for April 2010 was entered as the initial shoreline SHORL and the measured shoreline in April 2011 was entered in SHORM. The shoreline stretch measured in April 2011 consist of the 28 first coordinates, a beach stretch of 700 m, and the other coordinates are copied from the April 2008 SHORL file. The two calibration periods were run in connection to each other, and not separately, to find the calibration parameters that best matches the both periods together. The result of the second calibration period is shown in Figure 6:8.

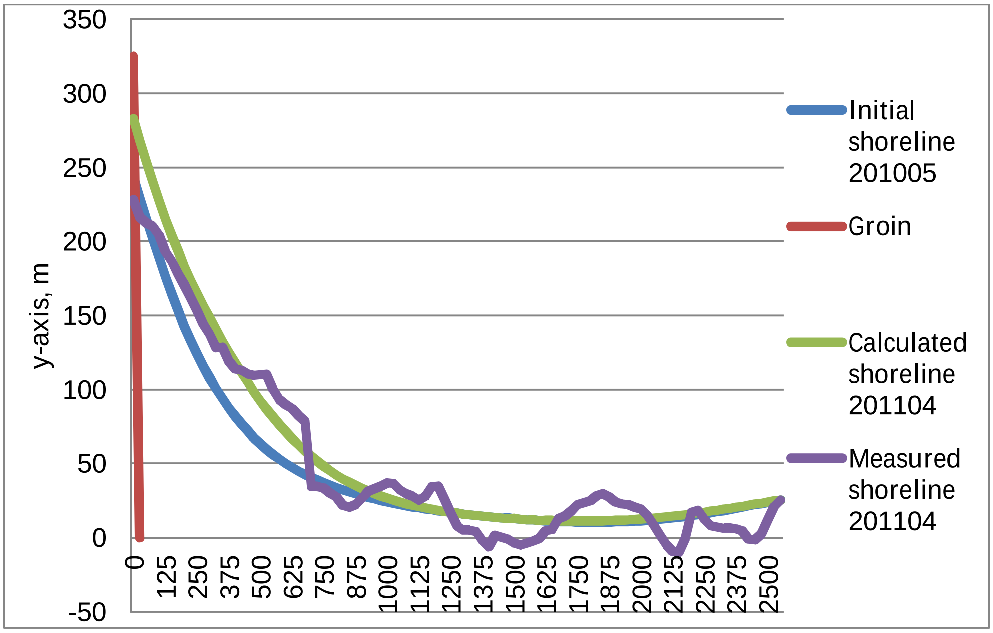

Figure 6:8 Model calibration during the period 20100501-20110430. The Initial shoreline (blue) is the calculated shoreline from the first calibration period. The output from the GENESIS calculation is plotted in green.

6.2.2. Model validation

When running the two validation periods none of the parameter values in the START file are changed, the validation years are used to check that the tuning of the calibration coefficients done during the calibration period to gain a reliable model is correct and correlates with the processes taking place over time. The permeability of the groin is set to 0.1 during the two validation periods, as discussed in chapter 6.1.4.

For the first validation period the measured position of the shoreline in May 2011 is entered into the SHORL file and the measured shoreline at June 2012 is entered into the SHORM file. The length of the measured coastline stretch in May 2011 consist of the 28 first coordinates, which gives a beach length of 700 m, and the rest are copied from the SHORC file from the second period of calibration. The length of the coastline stretch measured in June 2012 consist of the 31 first coordinates, which gives a beach length of 775 m, and the rest are copied from the initial shoreline of April 2008. The result from the first validation period is shown in Figure 6:9. The tweak at the end of the calculated shoreline (plotted in green) is disregarded from, as discussed in chapter 6.1.5.

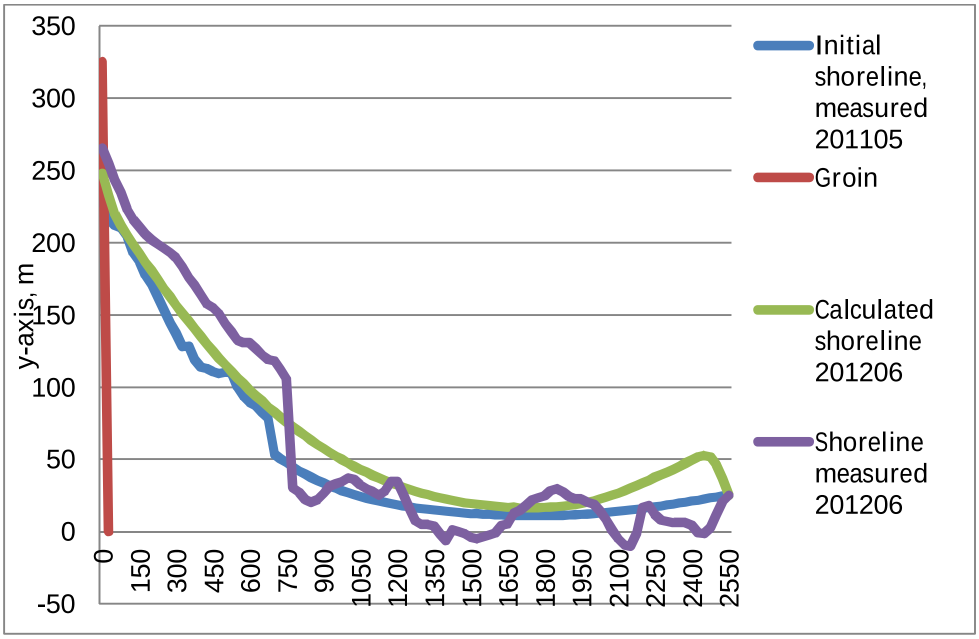

Figure 6:9 Model validation during the period 20110501-20120630. The output from the GENESIS calculation is plotted in green.

The calculated shoreline from the first verification period, found in the SHORC file, is entered into the SHORL file as the initial shoreline for the second verification period. The measured shoreline in January 2013 is entered into SHORM. The length of the measured coastline stretch in January 2013 consist of the 23 first coordinates, a beach length of 575 m, are measured and they were copied from June 2012 SHORC file. The result from the second calibration period is shown in Figure 6:10. There is not a big difference in the positions between the initial shoreline in June 2013 and the calculated shoreline in January 2013. Some comments can be made to the result; the period the model is run is shorter than the earlier periods of calibration and validation (which gives less time for change) and as seen in Figure 6:11 the accretion of sediment is low.

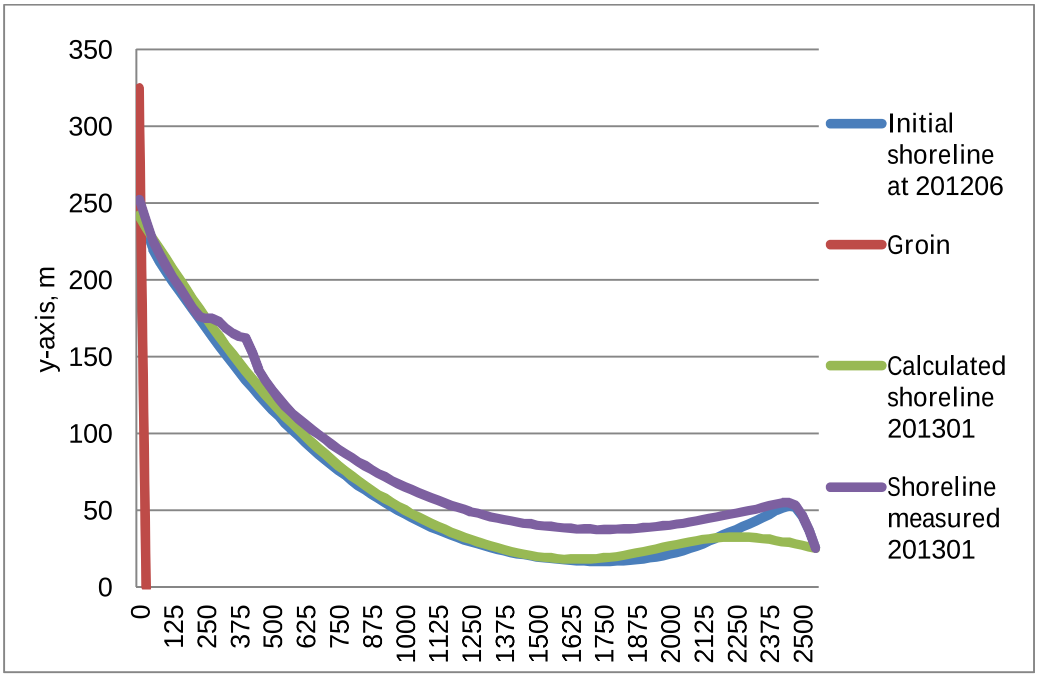

Figure 6:10 Model validation during the period 20120601-20130131. The Initial shoreline (blue) is the calculated shoreline from the first validation period. The output from the GENESIS calculation is plotted in green.

The WAVES file contains the wave data corresponding to the years of calibration and validation, from January 2008 until December 2012. Through the START file the wave data equivalent to the period of calibration or validation was chosen to simulate the wave climate and thereby the sediment transport. The wave data for January 2013 was not available when performing the modelling and instead GENESIS automatically starts over in the WAVES file. This gives that the last month of validation was performed with non-corresponding wave data, but the time period was considered small in comparison with the whole period of calibration and validation, and therefor an acceptable error. Though, this could also be a reason to that the calculated shoreline and the measured shoreline of January 2013, in Figure 6:10, is not correlating properly, the wave climate in January 2008 could differ from the wave climate in 2013.

6.2.3. Longshore sediment transport

The amount of sediment that is transported in and out of the model area during the model period is found in the OUTPT file. The calculated net transport of sand out of the area is measured around the edge of and through the groin and the net transport of sand into the model area is measured at the pinned beach. The sediment transport has a yearly net transportation direction to the left, from the pinned beach towards the groin. At the first calibration period the transportation out of the area at the groin was calculated to 214 000 m^3 and the transportation into the area by the pinned beach was 562 000 m^3. This gives an accreting of sediment in the area of 348 000 m^3 during the first calibration period. At the second calibration period the transportation out of the area at the groin was calculated to 174 000 m^3 and the transportation into the area by the pinned beach was 388 000 m^3. This gives an accreting of sediment in the area of 214 000 m^3 during the second calibration period. At the first verification period the transportation at the groin was calculated to 86 000 m^3 and the transportation into the area by the pinned beach was 373 000 m^3. This gives an accreting of sediment in the area of 287 000 m^3 during the first verification period. At the second verification period the transportation at the groin was calculated to 89 000 m^3 and the transportation into the area by the pinned beach was 111 000 m^3. This gives an accreting of sediment in the area of 22 000 m^3 during the second verification period. The sediment transport during the calibration and validation periods are shown in the bar diagram in Figure 6:11.

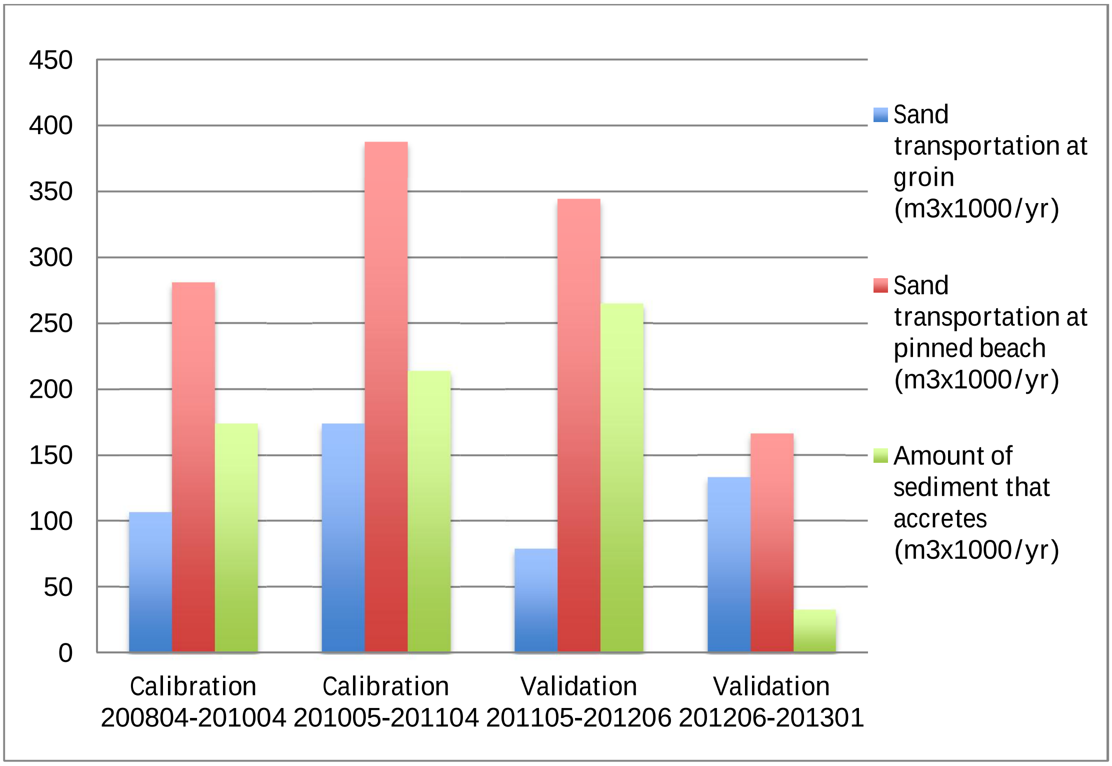

Figure 6:11 Transportation of sand alongshore at the model area, in by the pinned beach and out by the groin. The amount that accretes for the periods of calibration and validation is shown by the green bar. Sediment transport showed in amount per year.

The total net transport into the model area was calculated to be 1 434 000 m^3, which gives an average net transport of approximately 301 900 m^3/year.

6.2.4. Model sensitivity

By altering parameters in the START file the sensitivity of the model can be tested. If a small alteration to a parameter results in a large change in the calculated output an assessment regarding whether the quality of the verification is enough for a practical application can be made. During the calibration and validation periods some different values of parameters was changed, e.g. the position of the shoreline on the opposite side of the groin and the permeability of the groin, but with no drastic or unexpected change of the calculated shoreline position.

6.3. Measures to reduce erosion

One zero option and three different measures to reduce the erosion at Thuan An inlet was modelled. The different measures that were modelled have a main function to let more sediment pass the groin and thereby lessen the erosion on the northwest side of the groin. The model start was set to January 2013 and the wave data from the years 2008-2012, as applied during the calibration and validation, was used as input in the WAVES file. The decision to use the same wave data, and no earlier measured data, was based on that a good representation of the near future should lay in the near past since the recent climate changes then would be best represented. The model period was set to 20130101-20171231, with regards to the length of the time period of the wave data. The position of the shoreline at the beginning of the model period, measured at our field trip in the middle of January 2013, was entered through SHORL. In the SHORM file a set of random coordinates were entered since no measurements are done on the position of the shoreline in December 2017, but GENESIS still needs input data in the SHORM file to run the model.

No one of the calibrated and validated parameters in the START file were changed. The same time step dt=0.25 h as during the calibration and validation was used.

In the different charts showing the model result the position of the shoreline at the beginning and the end of the modelling period is plotted as well as the groin.

The amount of sediment transported into the model area from the south is the same in all of the different models; since the wave climate is the same in all of the simulations the transport will also be the same into the area. The transport to the north, out of the area, changes with regards to the design of the groin and a chart in the end of every chapter shows the difference in transport for the modelled measures.

6.3.1. Take no measure – zero option

The option to take no measures at all was modelled to gain a plausible future position of the shoreline to compare with the different suggestions of measures looked into. The groin length is kept the same as during the calibration and the validation periods and the permeability is set to 0.1. The position of the shoreline in the beginning and at the end of the simulation is shown in Figure 6:12. The sediment that is transported past the groin has a total calculated net amount of 1 087 000 m^3, which gives an average net transport of 217 400 m^3/year. The net transport of sand into the model area, from the south, is 1 355 000 m^3, which gives an average net transport of 271 000 m^3/year. This gives an accreting of sediment in the area of 268 000 m^3 during the five years of modelling, with an average accretion rate of 53 600 m^3/year.

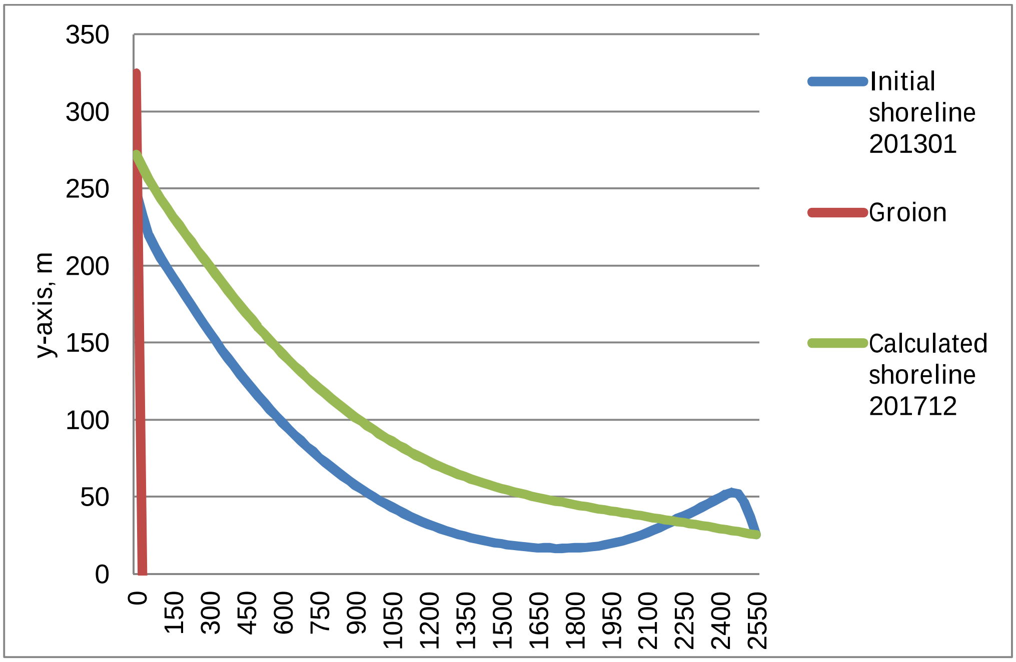

Figure 6:12 Model result if no changes in the groin design are made, model period 201301-201712

6.3.2. Reduction of groin length

The length of the groin is today 325 m. By shortening the length of the groin a higher rate of the sediment transported alongshore is enabled to pass around the edge of the groin. This will reduce the amount of sediment settling on the downside of the groin and increase the amount being transported into the inlet. Five different lengths were modelled; 275 m, 225 m, 175 m, 125 m and 75 m.

With the groin length set to 275 m the shoreline calculated by GENESIS has an appearance as shown in Figure 6:13. The calculated net transport of sand leaving the area around the edge of and through the groin is 1 274 000 m^3, which gives an average net transport of 254 800 m^3/year. The net transport of sand into the model area from the south is 1 355 000 m^3, which gives an average net transport of 271 000 m^3/year. This gives an accreting of sediment in the area of 81 000 m^3 during the five years of modelling, with an average accretion rate of 16 200 m^3/year.

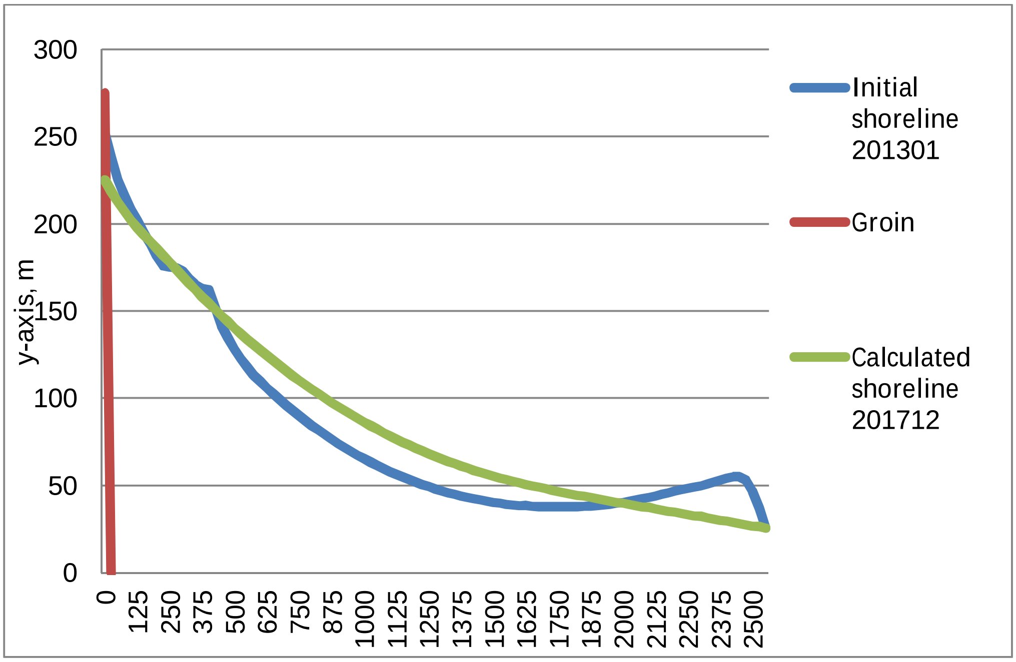

Figure 6:13 Model result when the length of the groin is reduced to 275 m, model period 20130101-20171231.

With the length of the groin set to 225 m the shoreline calculated by GENESIS has an appearance as shown in Figure 6:14. The calculated net transport of sand leaving the area around the edge of and through the groin is 1 448 000 m^3, which gives an average net transport of 289 600 m^3/year. The net transport of sand into the model area from the south is 1 355 000 m^3, which gives an average net transport of 271 000 m^3/year. This gives an erosion of sediment in the area of 93 000 m^3 during the five years of modelling, with an average erosion rate of 18 600 m^3/year.

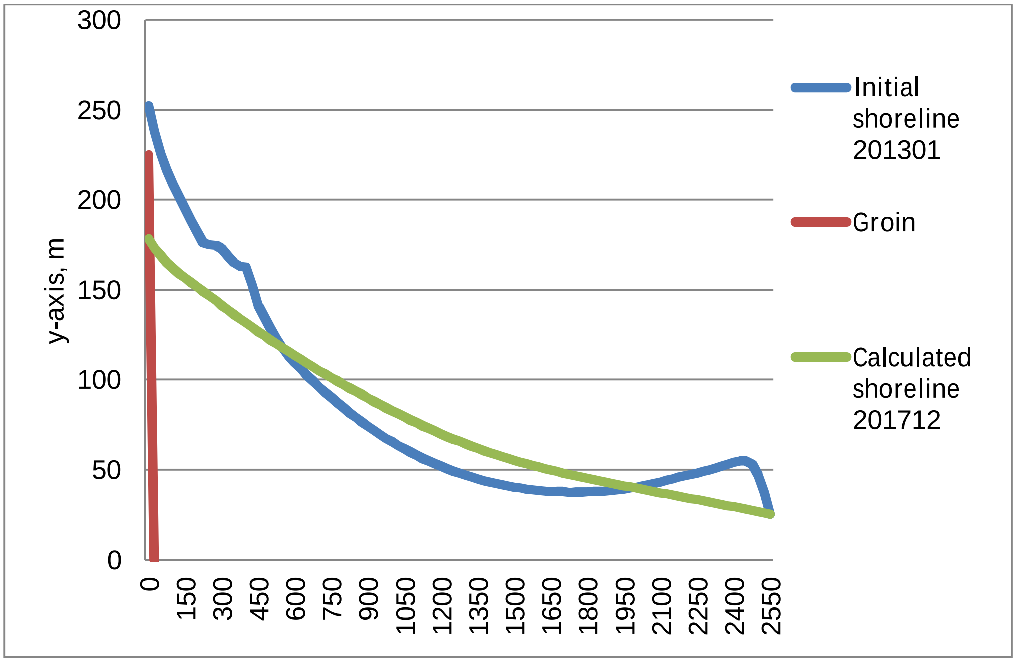

Figure 6:14 Model result when the length of the groin is reduced to 225 m, model period 20130101-20171231.

With the length of the groin set to 175 m the shoreline calculated by GENESIS has an appearance as shown in Figure 6:15. The calculated net transport of sand leaving the area around the edge of and through the groin is 1 595 000 m^3, which gives an average net transport of 319 000 m^3/year. The net transport of sand into the model area from the south is 1 355 000 m^3, which gives an average net transport of 271 000 m^3/year. This gives an erosion of sediment in the area of 240 000 m^3 during the five years of modelling, with an average erosion rate of 48 000 m^3/year.

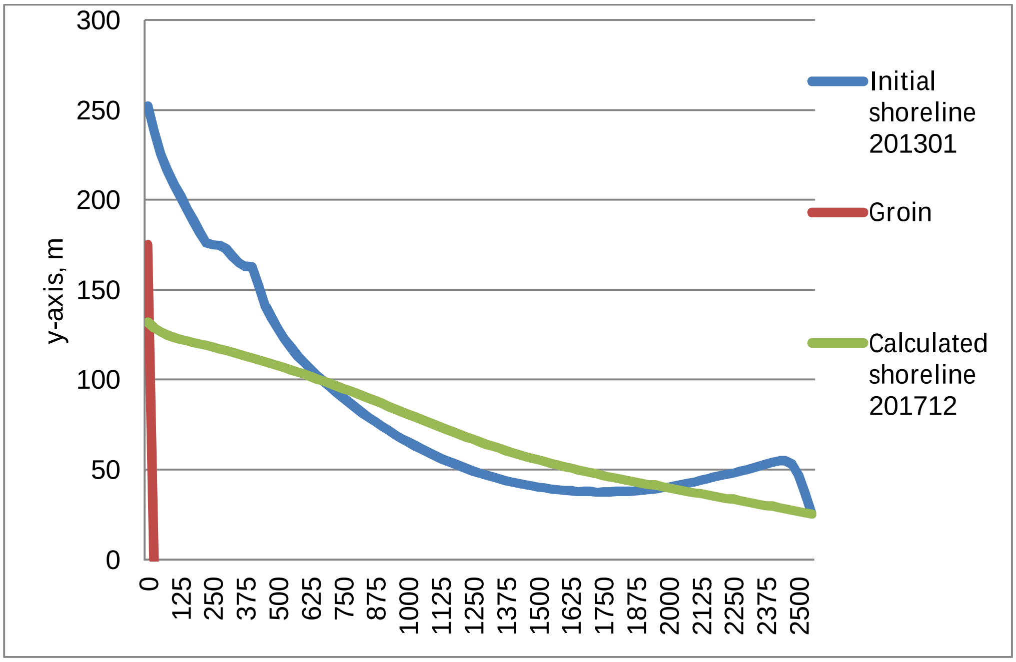

Figure 6:15 Model result when the length of the groin is reduced to 175 m, model period 20130101-20171231.

With the length of the groin set to 125 m the shoreline calculated by GENESIS has an appearance as shown in Figure 6:16. The calculated net transport of sand leaving the area around the edge of and through the groin is 1 700 000 m^3, which gives an average net transport of 340 000 m^3/year. The net transport of sand into the model area from the south is 1 355 000 m^3, which gives an average net transport of 271 000 m^3/year. This gives an erosion of sediment in the area of 345 000 m^3 during the five years of modelling, with an average erosion rate of 69 000 m^3/year.

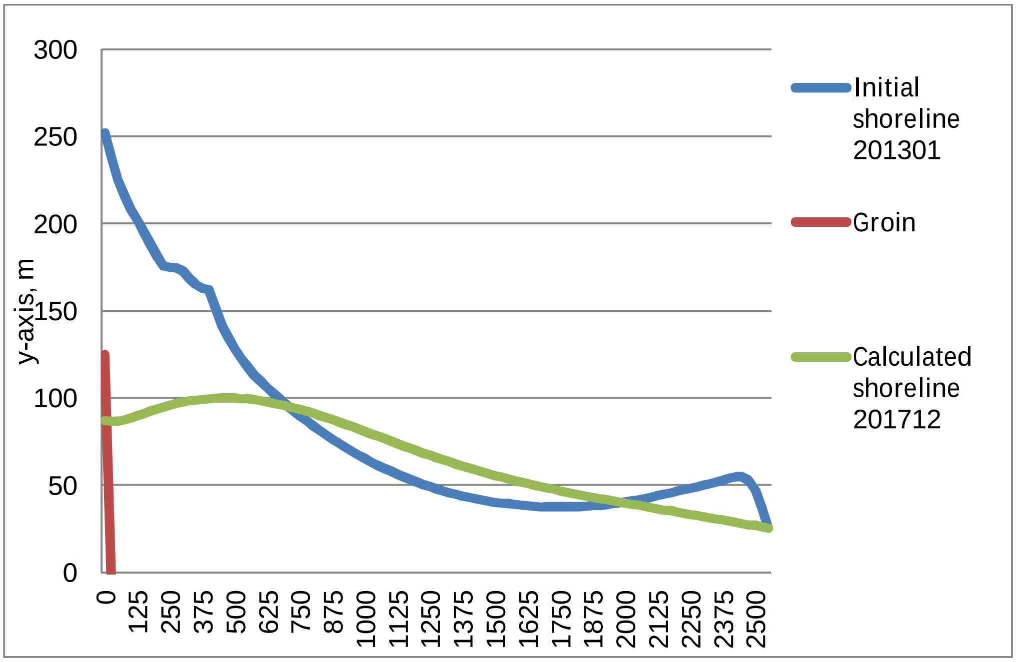

Figure 6:16 Model result when the length of the groin is reduced to 125 m, model period 20130101-20171231.

With the length of the groin set to 75 m the shoreline calculated by GENESIS has an appearance as shown in Figure 6:17. The calculated net transport of sand leaving the area around the edge of and through the groin is 1 740 000 m^3, which gives an average net transport of 348 000 m^3/year. The net transport of sand into the model area from the south is 1 355 000 m^3, which gives an average net transport of 271 000 m^3/year. This gives an erosion of sediment in the area of 385 000 m^3 during the five years of modelling, with an average erosion rate of 77 000 m^3/year.

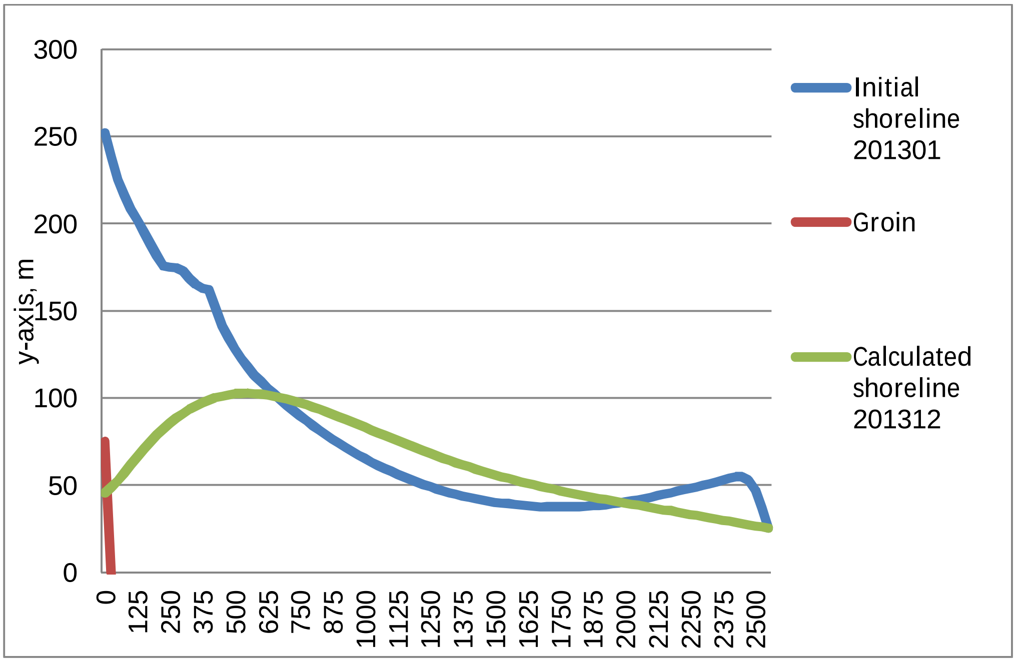

Figure 6:17 Model result when the length of the groin is reduced to 75 m, model period 20130101-20171231.

The calculated shoreline in Figure 6:17 gets a very distinct hump at a distance of approximately 500 m from the groin. The groin tip is located behind the initial shoreline, which gives that the movement of sediment takes plays along almost the whole y-axis. The position of the shoreline on the northwest side of the groin was set to 25 m at the y-axis and this can give that the erosion taking place on the northwest side of the groin is moved southeast, giving this distinctive look of the model output.

To compare the amount of sand that will pass by the groin and how much that enters by the pinned beach, at the different modelled groin lengths and the zero option, see Figure 6:18.

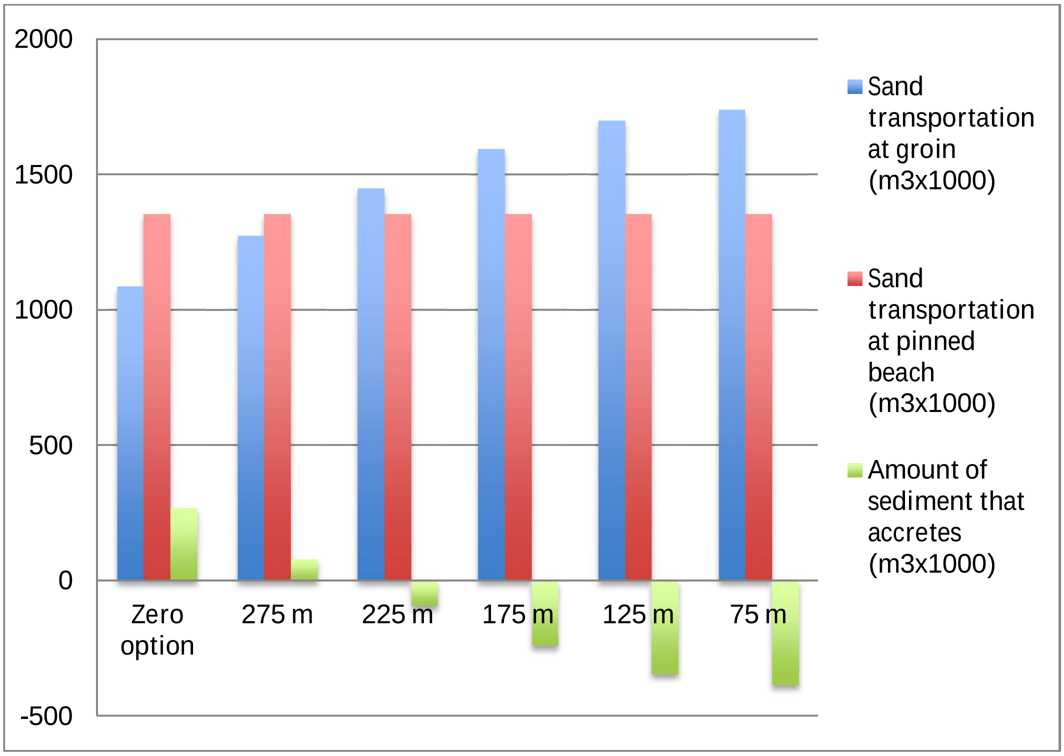

Figure 6:18 Transportation of sand alongshore, in and out of the model area, and the amount that accretes or erodes at different lengths of the groin. Model period 201301-201712

6.3.3. Higher permeability of the groin

The permeability can be made higher by removing some of the stones that the groin is built by and thereby create more space for sand to pass through the groin. Three different sizes on the permeability were modelled; 0.3, 0.4 and 0.6. The calculated position of the shoreline and the calculated net transport of sand on both edges of the model area are presented below for all of the different values of the permeability.

With the permeability of the groin set to 0.3 the shoreline calculated by GENESIS has an appearance as shown in Figure 6:19. The calculated net transport of sand leaving the area around the edge of and through the groin is 1 257 000 m^3, which gives an average net transport of 251 400 m^3/year. The net transport of sand into the model area from the south is 1 355 000 m^3, which gives an average net transport of 271 000 m^3/year. This gives an accreting of sediment in the area of 98 000 m^3 during the five years of modelling, with an average accretion rate of 19 600 m^3/year.

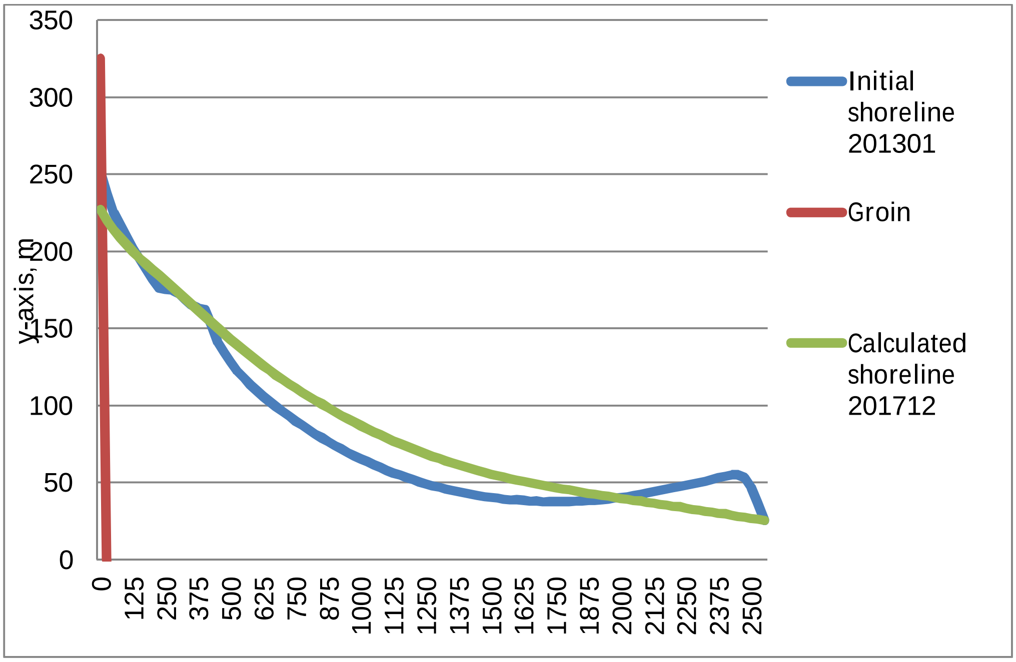

Figure 6:19 Model result with the permeability of the groin set to 0.3, model period 201301-201712

With the permeability of the groin set to 0.4 the shoreline calculated by GENESIS has an appearance as shown in Figure 7:20. The calculated net transport of sand leaving the area around the edge of and through the groin is 1 447 000 m^3, which gives an average net transport of 289 400 m^3/year. The net transport of sand into the model area from the south is 1 355 000 m^3, which gives an average net transport of 271 000 m^3/year. This gives an erosion of sediment in the area of 92 000 m^3 during the five years of modelling, with an average erosion rate of 18 400 m^3/year.

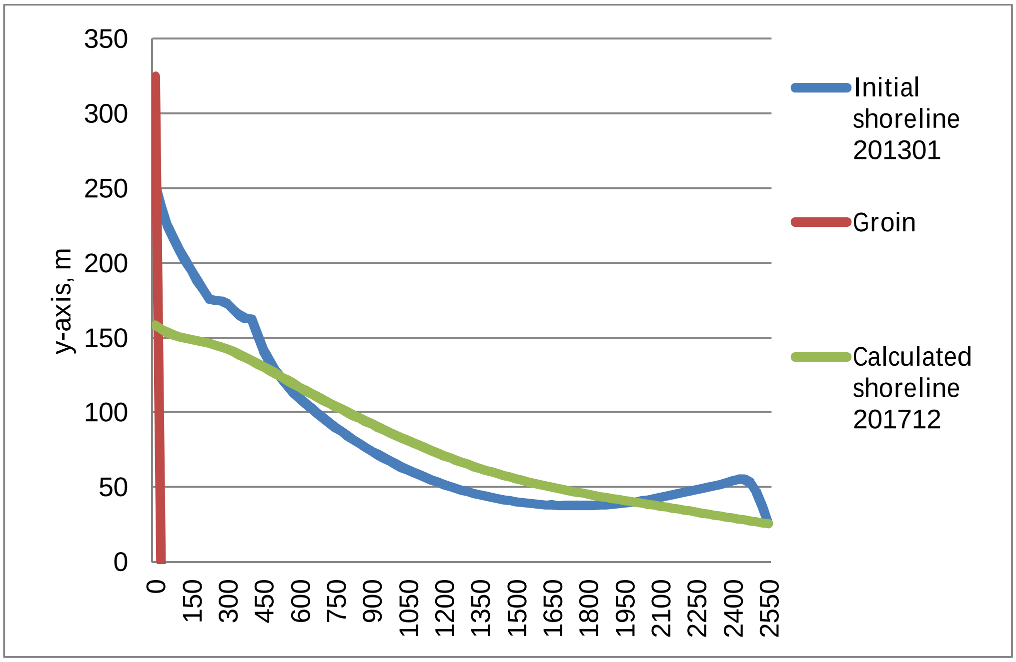

Figure 6:20 Model result with the permeability of the groin set to 0.4, model period 201301-201712

With the permeability of the groin set to 0.6 the shoreline calculated by GENESIS has an appearance as shown in Figure 6:21. The calculated net transport of sand leaving the area around the edge of and through the groin is 1 742 000 m^3, which gives an average net transport of 348 400 m^3/year. The net transport of sand into the model area from the south is 1 355 000 m^3, which gives an average net transport of 271 000 m^3/year. This gives an erosion of sediment in the area of 387 000 m^3 during the five years of modelling, with an average erosion rate of 77 400 m^3/year.

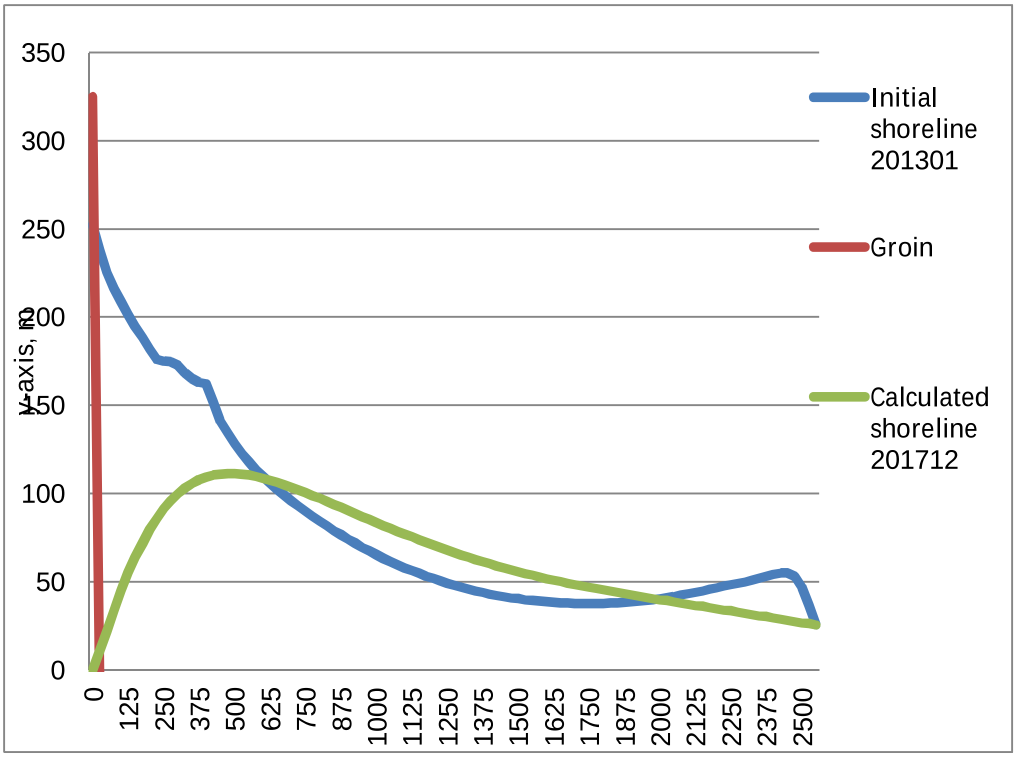

Figure 6:21 Model result with the permeability of the groin set to 0.6, model period 201301-201712

The appearance of the calculated shoreline in Figure 6:21 is similar to the calculated shoreline in Figure 6:17 and the explanation to the deviating look should be the same as earlier. The high value of the groin permeability gives that the erosion taking place on the northwest side of the groin starts to move to the southeast side. This gives a very distinctive raise in the amount of sediment that is transported out of the model area and results in the hump on the calculated shoreline. Higher values of the permeability were also modelled but the result is not presented here because it resembles the result of the permeability set to 0.6.

To compare the amount of sand that will be transported out of the area at the groin and how much that enters by the pinned beach, at the different modelled values of the permeability and the zero option, see Figure 6:22.

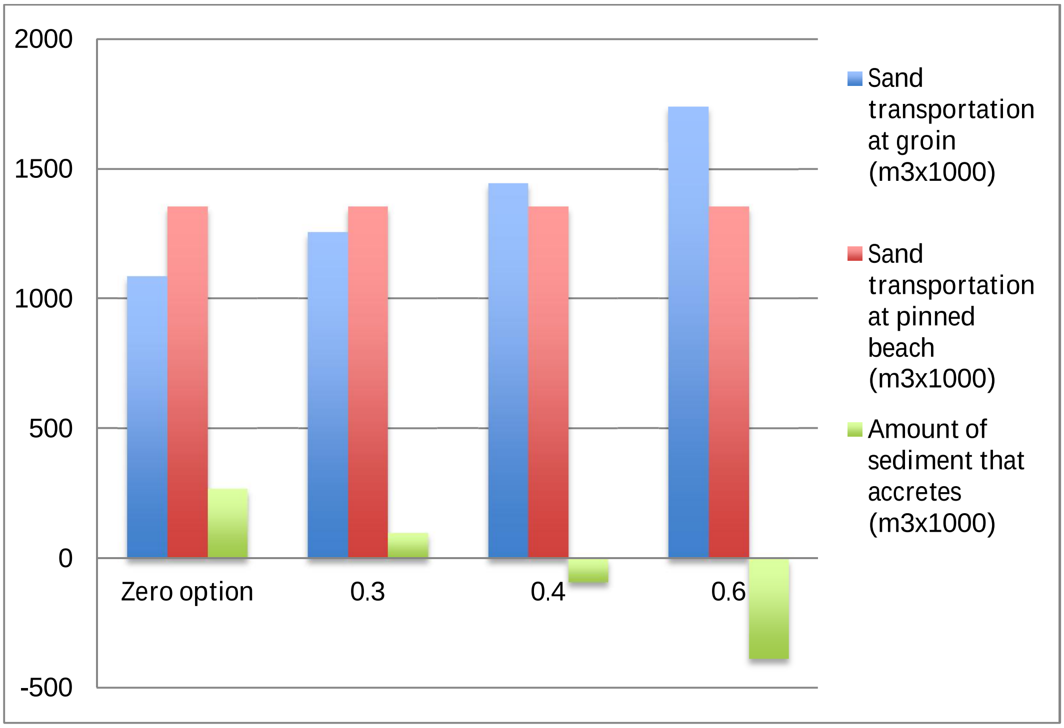

Figure 6:22 Transportation of sand alongshore, in and out of the model area, and the amount that accretes or erodes at different values of permeability of the groin. Model period 201301-201712

6.3.4. Sand dredging

Sand from the updrift of the groin is dredged to gain a better balance regarding the amount of sediment. The most suitable location to move the sand to is to the upside of the groin, which is towards the inlet. Thus, only the removal of the sand will be modelled, and not the adding of sediment to the inlet, since the inlet is not located in the modelling area. The solution with a combined dredging and infilling of sand will be discussed in chapter 8. Three different types of sand drainages was modelled, with regard to how many times the moving of sediment was conducted, for how many months the drainage lasted each time and how much sand that was removed. In GENESIS the simulation of the transport was carried out as a reversed beach fill, done by adding a negative value to the beach width to model a removal of sand instead of a infill.

The modelled position of the shoreline and the calculated net transport of the model area are presented below for all of the three different setups of sand dredging. The amount of sand that is dredged is calculated as the product of the closure depth plus the berm height (6+2 m), the alongshore length of the fill and the width of the removed area. The dredging is carried out in equal parts of the total width removed per time step of the set dredging period, with no regard to the wave climate (Hanson & Kraus 1989).

The first model of sand dredging is done at one occasion, from 20140301 to 20140701, a total of four months. The total area from were sand is removed has a length along the shoreline of 1450 m and a depth of the beach of 40 m. Figure 6:23 shows the initial shoreline at 20130101 and the shoreline calculated by GENESIS at 20171231.

The amount of sand that is transported out of the model area past the groin during the model period is 1 051 000 m^3, which gives an average net transport of 210 200 m^3/year. The amount that enters at the opposite side of the model area is 1 355 000 m^3, which gives an average net transport of 271 000 m^3/year. The amount of sediment that is dredged from the model area is 464 000 m^3 ($8 \cdot 1450 \cdot 40$). This gives an erosion of sediment in the area of 160 000 m^3 during the five years of modelling, with an average erosion rate of 32 000 m^3/year.

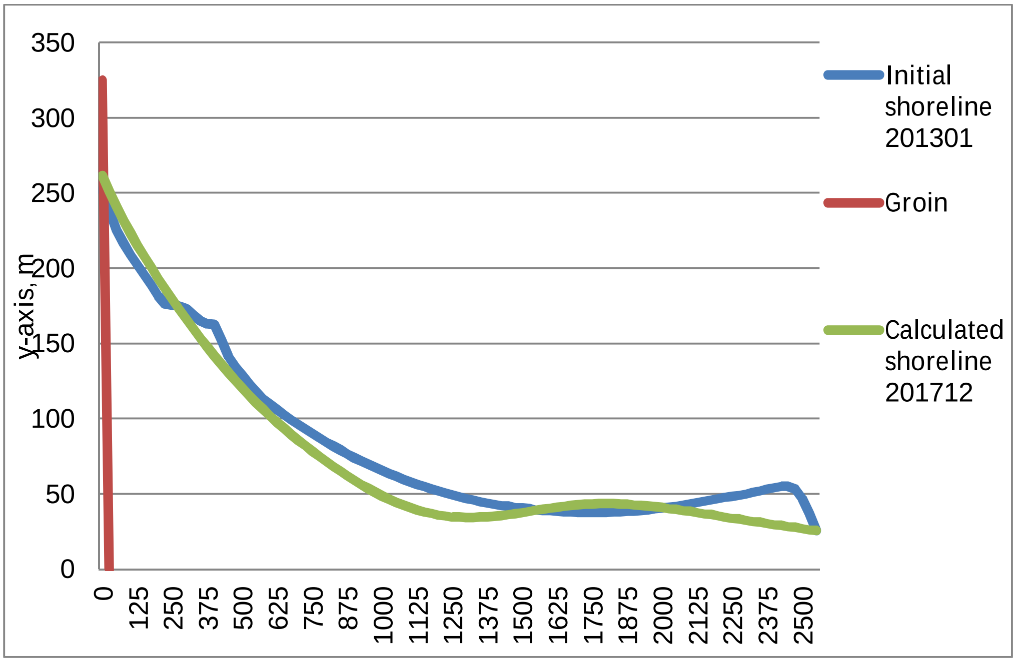

Figure 6:23 First model option regarding sand dredging from the downside of the groin, model period 201301-201712

The second model of sand dredging is done from two occasions of sand shifting, which are done from 20130201 to 20130601 and from 20160701 to 20161101, a total of four plus four months. The total area from were sand is removed at every dredging event has a length along the shoreline of 1450 m and a depth of the beach of 20 m. Figure 6:24 shows the initial shoreline at 20130101 and the shoreline calculated by GENESIS at 20171231.

The amount of sand that is transported out of the model area past the groin during the model period is 1 046 000 m^3, which gives an average net transport of 209 200 m^3/year. The amount that enters at the opposite side of the model area is 1 355 000 m^3, which gives an average net transport of 271 000 m^3/year. The amount of sediment that is dredged from the model area is 464 000 m^3 ($8 \cdot 1450 \cdot 20 \cdot 2$). This gives an erosion of sediment in the area of 155 000 m^3 during the five years of modelling, with an average erosion rate of 31 000 m^3/year.

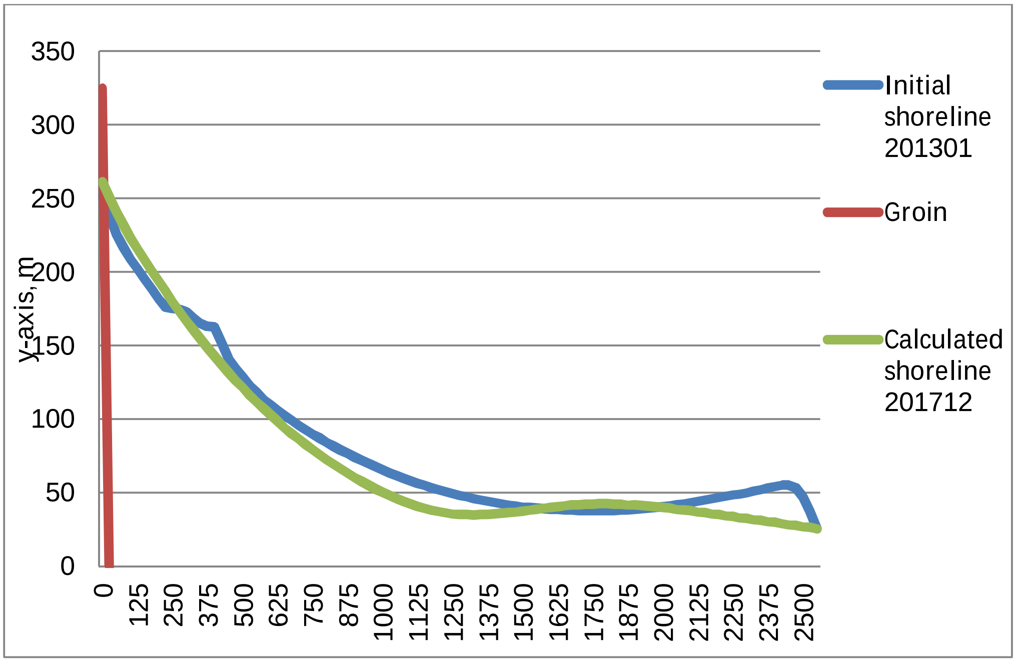

Figure 6:24 Second model option regarding sand dredging from the downside of the groin, model period 201301-201712

The third model of sand dredging is done from three occasions of sand shifting, which are done from 20130201 to 20130601, from 20140301 to 20140701 and from 20160701 to 20161101, thus each occasion has a length of four months. The length of area from were sand is removed has a length along the shoreline of 1450 m for the first and second transportation occasion and a length of 950 m for the last. The depth of the beach is 20 m for all three times of sand shifting. Figure 6:25 shows the initial shoreline at 20130101 and the shoreline calculated by GENESIS at 20171231.

The amount of sand that is transported out of the model area past the groin during the model period is 1 028 000 m^3, which gives an average net transport of 205 600 m^3/year. The amount that enters at the opposite side of the model area is 1 355 000 m^3, which gives an average net transport of 271 000 m^3/year. The amount of sediment that is dredged from the model area is 616 000 m^3 ($8 \cdot 1450 \cdot 20 \cdot 2 + 8 \cdot 950 \cdot 20$). This gives an erosion of sediment in the area of 289 000 m^3 during the five years of modelling, with an average erosion rate of 57 800 m^3/year.

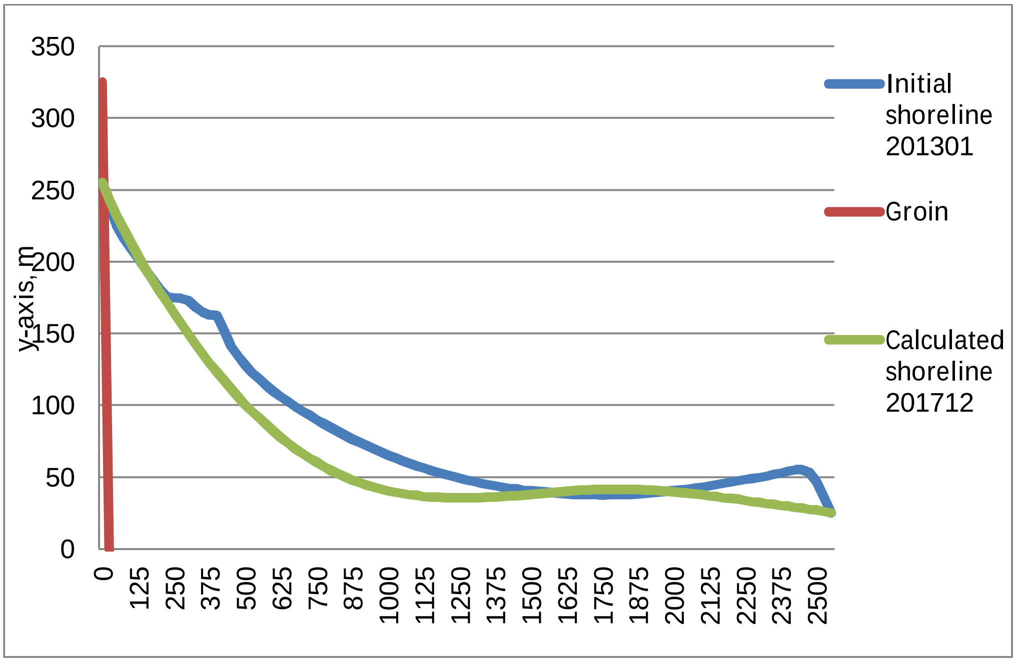

Figure 6:25 Third model option regarding sand dredging from the downside of the groin, model period 201301-201712

To compare the amount of sand that will pass by the groin, how much that enters by the pinned beach and the dredged sand volume, at the three different sand dredging options and the zero option, see Figure 6:26.

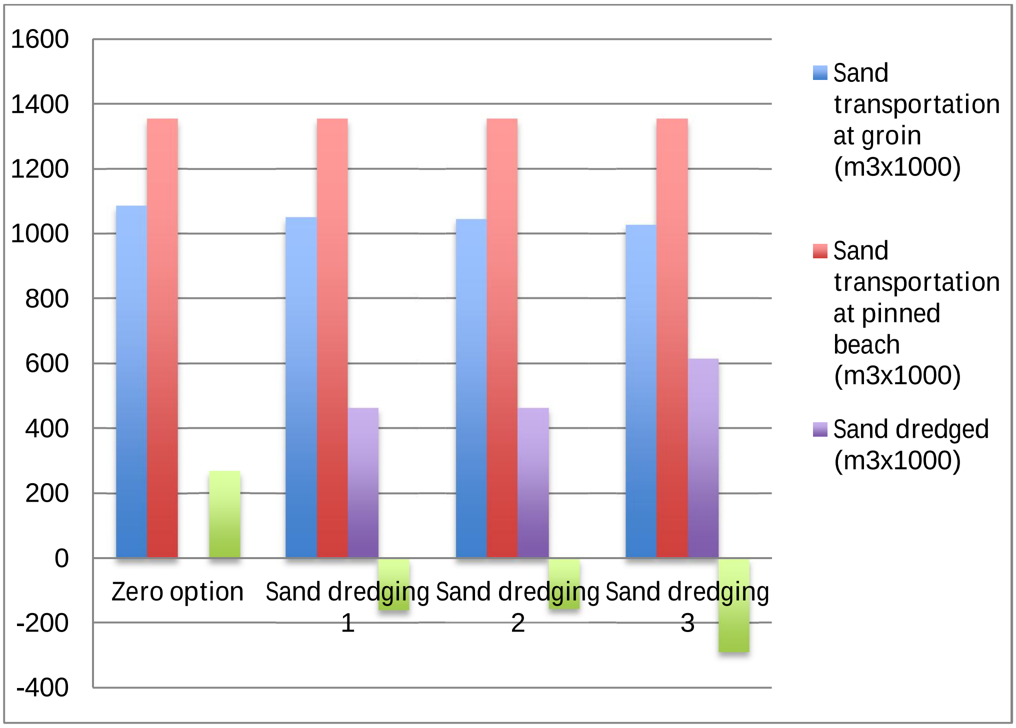

Figure 6:26 Transportation of sand alongshore, in and out of the model area, the dredged volume and the amount that accretes at the three different models of sand dredging. Model period 201301-201712.

7. Discussion

7.1. Introduction

At Thuan An inlet the erosion due to the construction of a groin has been studied. The model employed in this study describes how the coastline changes over time due to gradients in longshore sediment transport and how different measures to reduce the erosion at the northwest side of the groin affect the transport pattern. Only the coastline on the southeast side of the groin has been modelled, therefore it is hard to obtain a complete picture of how the sediment transport along the coastline all the way towards the Thuan An inlet is affected. This study discusses measures that could be useful to reduce erosion and stabilize the coastline of the area and the Thuan An inlet.

Three different measures to reduce the erosion along the coastline on the northwest side of the groin were studied, increasing the permeability of the groin, shortening of the groin and dredging sediment from the southeast side of the groin. The goal of this study was, using the modelling software GENESIS, to see how these three interventions affect the change of the coastline on the southeast side of the groin during the years 2013-2017, using data from 2008-2013 for calibrating and validating the model. The option of taking no measures was also modelled.

According to Hung et al. (2012) (see chapter 4.5) the length of the groin is rather short, therefore it does not contribute very much to stabilizing the Thuan An inlet, although it affects it indirectly by impacting the coastline southeast of the groin, which before could change significantly over a short period of time. It is estimated that the function of the groin might be lost by 2015 because of gradual accretion on the updrift side leading to that the amount of sediment that travel past the groin head will increase. This study looks at the conditions that the groin had in 2013 though, and analyses interventions needed at this time, not regarding that the groin would lose its function in 2015.

7.2. Considerations regarding different measures to reduce erosion

The most important elements to take into account when deciding what action to take due to erosion of a coastal area are timing and planning. The main aspects to keep in mind are technical, economic, environmental, legal, political, and social. When choosing which preventive measure to take to change the sediment transport pattern, knowledge about current hydraulic parameters (e.g., winds, waves, tides, and bathymetry), sedimentation (e.g., littoral transport processes), and navigation in the area are needed. The littoral transport regime is primarily affected by currents and wave climate, which are affected by the tidal climate and also by the wind climate, which is related to the monsoonal seasons of the area, see chapter 2.3.5. These factors all influence the longshore sediment transport and that is the main variable to investigate at Thuan An because it is the main mechanism that cause erosion along its' micro-tidal wave-dominated coast. Since the inlet stability is one of the key properties for the lagoon it is also important to look at factors affecting this, and how they are connected to, e.g., the tide at the time, see chapter 2.5.2.

The modelling employed in this report focuses mainly on reducing the erosion of the coastline on the northwest side of the groin. If the shoreline on both sides of the groin were to be modelled, factors affecting the stabilization of the inlet, such as currents outside the inlet, local and cross-sectional stability, waves and river flows should be investigated in a more detailed way, to get a picture of how strong forces the inlet can withstand. The stability can also be determined by looking at the relationship between tidal prism and the total annual littoral drift reaching the inlet. This relationship reveals the relative strength of the tidal currents to flush away the sediment that has been deposited by the longshore sediment transport in front of the inlet, see chapter 2.5.2. The Thuan An inlet has been classified to have ”fair to poor” stability, although these studies were performed before the groin was built. In the model made in this study the main focus is on reducing the erosion, i.e., letting more sediment pass the groin.

The calibration and validation of the model cannot be carried out with full accuracy. The lack of sufficient input data, concerning the amount of shoreline coordinates, gives that the resulting model does not correspond in total with the advancement of the coastline taking place in reality. The input of the position of the shoreline for the calibration, starting in April 2008, is made with the necessary amount of coordinates, since the performed measurements was carried out to a necessary length. This gives that the two calibration periods can be run with initial shoreline positions that correspond to reality. The two shorelines used to calibrate the calculated coastline position at the end of a period do not correspond to reality, since the measurements at those times were not executed to full length. The input data of initial shorelines and the shorelines used to evaluate the calculated coastline position for the two validation periods do not have a sufficient length. The resulting model is however assumed to have a satisfactorily precision and can be used to model different measures for the groin at Thuan An. When producing models it is common not to have enough input data, especially regarding corresponding wave data.

Evaluation of the result can also be made through a comparison of the value of the longshore sediment transport calculated by GENESIS with earlier estimations and calculations reported in different papers and publications. Calculations of the net sediment transport at the coast of Thuan An are presented in chapter 4.2.4, and the numbers that lay in the range of 300 000 - 700 000 m^3/year seems most plausible. Calculations done with the help of SEDTRAN with the wave data of 1991-2012 gives a net transport of 220 000 m^3/year, a bit lower than calculations that has been performed by Lam (2009) with the Bijker method that gives a net transport range of 250 000 - 330 000 m^3/year to the northwest. The net sediment transport during the periods of calibration and validation has an average annual value of 302 000 m^3/year to the northwest, which is considered to lie in the range of the earlier estimations of the longshore sediment transport. The later value is calculated with the wave data from 2008-2012.

As can be seen in Figure 6:12 the coastline will accrete on the southeast side of the groin with 268 000 m^3 of sediment between January 2013 and December 2017 if no measures are performed. This situation was modelled to get a picture of what will happen if the current situation will continue. The accretion seen in the figure implies that further erosion on the northwest side of the groin (and also at the Thuan An inlet) will take place during these years, resulting in that the groin is preventing sediment from passing it, leading to problems with erosion rather than of too much accretion at the Thuan An inlet. The option of not doing anything and relocating is therefore found not to be a suitable action due to that the continuing erosion will damage the tourist beach and constructions, such as roads, buildings, electricity lines and so on.

Changes of the Thuan An inlet would consequently have a strong impact on the socio-economic situation of the lagoon. Since approximately one third of the population in the Hue province are dependent on the environment of the lagoon (see chapter 3.1.4) because fishery, aquaculture and agriculture are the basis of their livelihood, and also because they live and have their residences in the area of the lagoon, it is very important to keep stable conditions at the inlet and the coastline. Both coastal erosion, which could e.g. lead to changing the existing inlet and/or opening another inlet, and extensive sedimentation that could move, change or even close an inlet could have a great impact on the lagoon. Two of the main threats to the activities of the lagoon are flooding (that can lead to e.g. pollution, destruction of crops, habitats and properties and changed water conditions) and changes of the inlets of the lagoon (which can change the physical and ecological properties of the lagoon such as water exchange, salinity, water quality and biodiversity). The inlets are also used for marine traffic in and out from the lagoon. Severe erosion will also be a danger to buildings located close to the coastline, to tourist areas and recreational beaches.

The conclusion of this is that further measures to enhance the sediment transport past the groin are needed. The three different interventions modelled in this study were tested separately to see the specific result of each one of them. The outcome from these measures regarded to be most important is to stabilize the downdrift coastline to the extent that the situation at the Thuan An inlet provides sustainable conditions for marine traffic into and out from the lagoon and for aquaculture, agriculture and fishery in and around the lagoon. To be able to make a sediment budget calculation for the whole area at Thuan An inlet, including both sides of the groin, the model area would have to be extended to the northwest, past the inlet. Also, a calculation regarding how much of the transported sediment that will accrete in the inlet, along with the amount transported there by the rivers, and how much that will end up somewhere else. Thus, the focus of this thesis has been to model different measures that will counteract the erosion of Thuan An inlet by letting more sediment pass by the groin.

7.3. Discussion of model results

One measure was to see how the sediment transport past the groin differed when changing the length of the groin. The current length of the groin is 325 m and the different lengths that were tested were 275, 225, 175, 125 and 75 m and the model results can be seen in Figure 6:13 to 6:17. Looking at Figure 6:13 and 6:14 it can be seen that the sediment transport goes from accretion to erosion on the southeast side of the groin when changing the length of the groin from 275 to 225 m, since the calculated shoreline of 2017 has retreated compared to the initial one in 2013. However, when the length of the groin is reduced to 125 m a tendency for the coastline to decline towards the groin can be seen, see Figure 6:16. This decline is even stronger with a groin length of 75 m, see Figure 6:17. This decline can be a result of the groin length being relatively short, which gives a large sediment transport past the groin that could induce erosion on the southeast side of the groin as well. The erosion of the shoreline is moved from the northwest side of the groin into the southeast side, therefore this decline in the coastline occurs. This could be initiated through that the level of the coastline on each side of the groin were unequal, and the level of the shoreline on the northwest side of the groin was modelled as 100 m less than the groin.

Another measure that was modelled is the possibility of increasing the permeability of the groin, for example by making a few holes in the groin (by removing stones that it is built of) so that sediment may travel through it. The stability of the groin, towards e.g. storms and strong currents, when increasing the permeability has to be considered as well. A permeability of the groin of 0.3, 0.4 and 0.6 was modelled and the different resulting coastlines can be seen in Figure 6:19 to 6:21. With a permeability of 0.3 the coastline close to the groin does not move that much (see Figure 6:19) during the modelling period from 2013-2017, in comparison to the shoreline position in 2013. The sediment accretion rate per year is lower than the rate when not taking any measures (the zero option) and the graph shows that the accretion takes place approximately 500 m from the groin, giving that a sediment balance has been reached near the groin. With a permeability of 0.4 however, the calculated coastline has retreated approximately 100 m just adjacent to the groin, which shows that more sediment is passing through it than with the previously modelled permeability. When increasing the permeability to 0.6 a sharp bend in the coastline towards the base of the groin is obtained. This is most probably a result of the larger amount of sediment that passes through the groin, giving that the erosion from the northwest side of the groin moves to the southeast, as mentioned regarding the measure to shorten the groin. Looking at Figure 6:22 the amount of sediment that accredits is increasing in a non-proportional way between the permeability values of 0.4 and 0.6. These values have been run twice in the model, but the same result was obtained.

The last measure that was studied was sand dredging on the southeast side of the groin. Only the removal (and not where to deposit it) of sediment was studied and three different strategies of dredging were looked into, to see the difference in how the coastline changes depending on amount of sediment removed and of the number of dredging occasions. Since the coastline on northwest side of the groin is eroding it could be a suitable option to deposit the sediment there, depending on the development of this part of the beach and the Thuan An inlet. The first dredging was done through one excavation of sediment, removing a total of 464 000 m^3 of sediment. The second model of dredging was during two occasions, removing 464 000 m^3 of sediment in total. Even though the same amount was dredged during the two model periods, the second period has a slightly smaller net sediment transport past the groin, resulting in a noticeable but marginally less erosion rate. The third and last model of dredging was done from three occasions of sand dredging, resulting in a total sediment removal of 616 000 m^3. In Figure 6:27 it can be seen that the net sediment transport at the groin is approximately the same and the total sediment budget for the three different dredging models gives an erosion of sediment in the model area. To have a consistent modelling it would have been better to only change the amount of sand dredged and not also the number of sediment removals, and thereby only change one parameter. This would have made it easier to see how different dredging volumes affect the coastline development.

The Figures 6:18, 6:22 and 6:26 shows the net sediment transport in and out of the model area, with the amount of sediment that erodes or accretes, during the modelling of the different measures. If no measures are made, the average annual accretion of sediment are modelled to be 53 600 m^3/year and this number is compared to the size of the erosion and accretion made during modelling of the different measures. The size of the net sediment transport in the model area have to be put into a sediment budget concerning the area on both sides of the groin, including the inlet at Thuan An, to get a total evaluation regarding a suitable transport rate to gain a balanced deposition of sediment.

7.4. Future solutions

With the knowledge of the amount of sediment that erode on the northwest side of the groin, at the inlet, these described measures to reduce erosion can be adapted to change the amount of sediment that passes by the groin, to prevent the northwest side of the coastline from eroding and to stabilize the Thuan An Inlet. When the choice regarding that measures are needed to change the sediment transport pattern, the first question that needs to be answered is what shore protection alternative that is suitable for the current situation. Since no pre-investigation material made before constructing the groin in 2008 has been found it is difficult to know the background ideas and facts regarding the structure.

Previously discussed literature (see chapter 4.5) has proposed and analysed and the solution of stabilizing the inlet with a jetty and dredging the inlet to keep it open, as well as constructing two long jetties on each side of the inlet and combining that with beach nourishment. The latter alternative is, however, found to be the most expensive option. Doing only beach nourishment will temporarily re-establish the beach, though the longshore sediment transport will continue and therefore the nourishment will have to be done repeatedly. The option of building only one groin is not recommended as a good alternative due to the downstream erosion that it creates according to Tung (2001). A more modern approach when designing a groin is to make it permeable to let sediment pass through it. It also stated that a hard measure, like a groin, does not solve the erosion problem, it only moves it.

A groin field could be a better solution than just one groin. A groin field, consisting of five groins placed just south of the narrowest part of the inlet, was constructed in 1997 to prevent the ongoing erosion at the Thuan An inlet at the time (see chapter 4.5). The groin field only lasted one year after it was constructed though, it was damaged and lost its function due to constructional errors, see chapter 3.2.2. This reveals the importance of considering the distances between the groins and their location when designing a groin field. Also, placing the groin field south of Hoa Duan might cause problems due to that too little sand will be transported past the groins and the Hoa Duan inlet might open up again, which it did in 1999. A new construction of a groin field could be considered and the lessons learned from the previous groin field should be used. To establish a preliminary investigation, which was not done before the last groin field was built, is of outmost importance taking into consideration the layout and location of the groin field.

When deciding if using only one measure or a combination of different measures, financial and legal aspects have to be considered as well as required maintenance to obtain and maintain the desired result (e.g., the availability of people able to work with it), and also ecological and environmental aspects. The modelling period of this study encompassed five years, but for acquiring a sustainable solution looking at a longer perspective of how the sediment transport will change is needed. Another question to take into consideration is the economical viability of the project, comparing costs with expected life expectancy of the solution.

A combination of measures to reduce erosion can therefore be an interesting option. Combining sand dredging (which is an intervention easy to adapt to changing conditions over time, such as differences in the longshore sediment transport due to climate changes) with shortening of the groin or changing the permeability of the groin (which demands less continuous maintenance) could be a combination of preventive measures that can be adapted to the current situation. How to combine these preventions has to be adjusted to the local premises arriving at a solution that is fundable and manageable according to, e.g., during which time periods during the year that dredging is possible, which dredging alternatives that are possible and how the properties of the groin changes over time. However, to make optimal interventions the coastline on both sides of the groin has to be modelled to make a proper evaluation of the sediment transport budget. Also considerations regarding other factors controlling the stability of the Thuan An inlet, e.g. river floods and the high velocity flow jets that are created in connection with these floods that maintain the inlet, have to be taken into account. Due to time limitations this was not done in this study. To create a good solution a further pre-study is necessary.

8. Conclusion

The main objective in this study was to analyse how different measures to reduce coastal erosion affect sediment transport. The location that was looked at was the coastline outside of the Tam Giang-Cau Hai lagoon outside of Hue in central Vietnam, which has two inlets; Tu Hien and Thuan An. The sediment transport past the groin located outside of the Thuan An inlet was modelled and the aim was to see how different measures to reduce erosion affected the sediment transport.

The interventions analysed were shortening the groin, increasing the permeability of the groin and dredging sand from the southeast side of the groin. Also the scenario where no measures are taken was modelled. The conclusion was that measures against the erosion are needed; otherwise the ongoing erosion might cause great problems for people living around the lagoon and earning their livelihood from it, due to the risk of e.g. flooding, changed water transport patterns and changed water quality.

The conclusion from the model results was that a combination of the different measures could be a solution to change the sediment transport past the groin so that more sediment passes to reduce the erosion of the inlet, but enough sediment remains on the updrift side to prevent erosion of the beach northeast if Thuan An (the purpose of groin when it was built). Combining e.g. sand dredging with shortening the groin or increasing the permeability of the groin could be a solution, or creating a groin field. These measures have to be adapted to local premises, such as how often dredging is possible and how the properties of the groin changes over time, to a functional solution. Also factors controlling the stability of the Thuan An inlet have to be taken into account. Though, to create an optimal solution to reduce the erosion of Thuan An inlet both the northwest and the southeast side of the groin need to be modelled to get the possibility to evaluate the sediment transport pattern.

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10. Appendices

10.1. Appendix 1

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*******************************************************************
**
 * INPUT FILE START.DAT TO GENESIS VERSION 3.0 - CREATED BY
GENESIS95 *
*******************************************************************
**
A----------------------------- MODEL SETUP -----------------------------A
A.1  RUN TITLE
start200804-201004
A.2  INPUT UNITS (METERS=1, FEET=2): ICONV
1
A.3  TOTAL NUMBER OF CALCULATION CELLS AND CELL LENGTH: NN,
DX
103 25
A.4  GRID CELL NUMBER WHERE SIMULATION STARTS AND NUMBER
OF CALCULATION CELLS (N = -1 MEANS N = NN): ISSTART, N
1 103
A.5  VALUE OF TIME STEP IN HOURS: DT
0.25
A.6  DATE WHEN SHORELINE SIMULATION STARTS (DATE FORMAT
YYMMDD: 1 MAY 1992 = 920501): SIMDATS
080401
A.7  DATE WHEN SHORELINE SIMULATION ENDS OR TOTAL NUMBER
OF TIME STEPS (DATE FORMAT YYMMDD: 1 MAY 1992 = 920501):
SIMDATE
100431
A.8  NUMBER OF INTERMEDIATE PRINT-OUTS WANTED: NOUT
0
A.9  DATES OR TIME STEPS OF INTERMEDIATE PRINT-OUTS (DATE
FORMAT YYMMDD: 1 MAY 1992 = 920501, NOUT VALUES): TOUT(I)

A.10 NUMBER OF CALCULATION CELLS IN OFFSHORE CONTOUR
SMOOTHING WINDOW (ISMOOTH = 0 MEANS NO SMOOTHING,
ISMOOTH = N MEANS STRAIGHT LINE. RECOMMENDED DEFAULT
VALUE = 11): ISMOOTH
11
A.11 REPEATED WARNING MESSAGES (YES=1, NO=0): IRWM
1
A.12 LONGSHORE SAND TRANSPORT CALIBRATION COEFFICIENTS: K1,
K2
0.11 0.10
A.13 PRINT-OUT OF TIME STEP NUMBERS? (YES=1, NO=0): IPRINT
```

```
1
B----------------------------- WAVES -------------------------------------B
B.1 WAVE HEIGHT CHANGE FACTOR. WAVE ANGLE CHANGE FACTOR
AND AMOUNT (DEG) (NO CHANGE: HCNGF=1, ZCNGF=1, ZCNGA=0):
HCNGF, ZCNGF, ZCNGA
1 1 0
B.2 DEPTH OF OFFSHORE WAVE INPUT: DZ
45
B.3 IS AN EXTERNAL WAVE MODEL BEING USED (YES=1, NO=0): NWD
0
B.4 COMMENT: IF AN EXTERNAL WAVE MODEL IS NOT BEING USED,
CONTINUE TO B.9
B.5 NUMBER OF SHORELINE CALCULATION CELLS PER WAVE MODEL
ELEMENT: ISPW
1
B.6 NUMBER OF HEIGHT BANDS USED IN THE EXTERNAL WAVE
MODEL TRANSFORMATIONS (MINIMUM IS 1, MAXIMUM IS 9): NBANDS
1
B.7 COMMENT: IF ONLY ONE HEIGHT BAND WAS USED CONTINUE TO
B.9
B.8 MINIMUM WAVE HEIGHT AND BAND WIDTH OF HEIGHT BANDS:
HBMIN, HBWIDTH
0 0
B.9 VALUE OF TIME STEP IN WAVE DATA FILE IN HOURS (MUST BE AN
EVEN MULTIPLE OF, OR EQUAL TO DT): DTW
3
B.10 NUMBER OF WAVE COMPONENTS PER TIME STEP: NWAVES
1
B.11 DATE WHEN WAVE FILE STARTS (FORMAT YYMMDD: 1 MAY 1992 =
920501): WDATS
080101
C----------------------------- BEACH ----------------------------------C
C.1 EFFECTIVE GRAIN SIZE DIAMETER IN MILLIMETERS: D50
0.41
C.2 AVERAGE BERM HEIGHT FROM MEAN WATER LEVEL: ABH
2
C.3 CLOSURE DEPTH: DCLOS
6
C.4 ANY OPEN BOUNDARY? (NO=0, YES=1): IOB
1
C.5 COMMENT: IF NO OPEN BOUNDARY, CONTINUE TO D.
C.6 TIME BASE IN BOUNDARY MOVEMENT SPECIFICATION(S)?
(SIMULATION PERIOD = 1, DAY = 2, TIME STEP = 3): ITB
1
C.7 OPEN BOUNDARY ON LEFT-HAND SIDE? (NO=0, YES=1): IOB1
0
```

C.8 COMMENT: IF A GROIN ON LEFT-HAND BOUNDARY, CONTINUE TO C.10.
C.9 BOUNDARY MOVEMENT PER TIME BASE ON LEFT-HAND BOUNDARY, IN SYSTEM OF UNITS SPECIFIED IN A.2 (PINNED BEACH => YC1 = 0): YC1
0
C.10 OPEN BOUNDARY ON RIGHT-HAND SIDE? (NO=0, YES=1): IOBN
1
C.11 COMMENT: IF A GROIN ON RIGHT-HAND BOUNDARY, CONTINUE TO D.
C.12 BOUNDARY MOVEMENT PER TIME BASE ON RIGHT-HAND BOUNDARY, IN SYSTEM OF UNITS SPECIFIED IN A.2 (PINNED BEACH => YCN = 0): YCN
0
D--------------------- NON-DIFFRACTING GROINS ----------------------------D
D.1 ANY NON-DIFFRACTING GROINS? (NO=0, YES=1): INDG
1
D.2 COMMENT: IF NO NON-DIFFRACTING GROINS, CONTINUE TO E.
D.3 NUMBER OF NON-DIFFRACTING GROINS: NNDG
1
D.4 GRID CELL NUMBERS OF NON-DIFFRACTING GROINS (NNDG VALUES): IXNDG(I)
1
D.5 LENGTHS OF NON-DIFFRACTING GROINS FROM X-AXIS (NNDG VALUES): YNDG(I)
700
E------------- DIFFRACTING (LONG) GROINS AND JETTIES --------------------E
E.1 ANY DIFFRACTING GROINS OR JETTIES? (NO=0, YES=1): IDG
0
E.2 COMMENT: IF NO DIFFRACTING GROINS, CONTINUE TO F.
E.3 NUMBER OF DIFFRACTING GROINS/JETTIES: NDG
0
E.4 GRID CELL NUMBERS OF DIFFRACTING GROINS/JETTIES (NDG VALUES): IXDG(I)

E.5 LENGTHS OF DIFFRACTING GROINS/JETTIES FROM X-AXIS (NDG VALUES): YDG(I)

E.6 DEPTHS AT SEAWARD END OF DIFFRACTING GROINS/JETTIES(NDG VALUES): DDG(I)

F------------------------ ALL GROINS/JETTIES ------------------------------F
F.1 COMMENT: IF NO GROINS OR JETTIES, CONTINUE TO G.
F.2 PERMEABILITIES OF ALL GROINS AND JETTIES (NNDG+NDG VALUES): PERM(I)
0

F.3 IF GROIN OR JETTY ON LEFT-HAND BOUNDARY, DISTANCE FROM SHORELINE OUTSIDE GRID TO SEAWARD END OF GROIN OR JETTY: YG1
350
F.4 IF GROIN OR JETTY ON RIGHT-HAND BOUNDARY, DISTANCE FROM SHORELINE OUTSIDE GRID TO SEAWARD END OF GROIN OR JETTY: YGN

G---------------------- DETACHED BREAKWATERS ----------------------------G
G.1 ANY DETACHED BREAKWATERS? (NO=0, YES=1): IDB
0
G.2 COMMENT: IF NO DETACHED BREAKWATERS, CONTINUE TO H.
G.3 NUMBER OF DETACHED BREAKWATERS: NDB
0
G.4 ANY DETACHED BREAKWATER ACROSS LEFT-HAND CALCULATION BOUNDARY (NO=0, YES=1): IDB1

G.5 ANY DETACHED BREAKWATER ACROSS RIGHT-HAND CALCULATION BOUNDARY (NO=0, YES=1): IDBN

G.6 GRID CELL NUMBERS OF TIPS OF DETACHED BREAKWATERS: (2 * NDB - (IDB1+IDBN) VALUES): IXDB(I)

G.7 DISTANCES FROM X-AXIS TO TIPS OF DETACHED BREAKWATERS (1 VALUE FOR EACH TIP SPECIFIED IN G.6): YDB(I)

G.8 DEPTHS AT DETACHED BREAKWATER TIPS (1 VALUE FOR EACH TIP SPECIFIED IN G.6): DDB(I)

G.9 TRANSMISSION COEFFICIENTS FOR DETACHED BREAKWATERS (NDB VALUES): TRANDB(I)

H---------------------------- SEAWALLS ---------------------------------H
H.1 ANY SEAWALL ALONG THE SIMULATED SHORELINE? (YES=1, NO=0): ISW
0
H.2 COMMENT: IF NO SEAWALL, CONTINUE TO I.
H.3 GRID CELL NUMBERS OF START AND END OF SEAWALL (ISWEND = -1 MEANS ISWEND = N): ISWBEG, ISWEND

I---------------------------- BEACH FILLS -------------------------------I
I.1 ANY BEACH FILLS DURING SIMULATION PERIOD? (NO=0, YES=1): IBF
0
I.2 COMMENT: IF NO BEACH FILLS, CONTINUE TO J.

I.3 NUMBER OF BEACH FILLS DURING SIMULATION PERIOD: NBF
0
I.4 DATES OR TIME STEPS WHEN THE RESPECTIVE FILLS START (DATE FORMAT YYMMDD: 1 MAY 1992 = 920501, NBF VALUES): BFDATS(I)

I.5 DATES OR TIME STEPS WHEN THE RESPECTIVE FILLS END (DATE FORMAT YYMMDD: 1 MAY 1992 = 920501, NBF VALUES): BFDATE(I)

I.6 GRID CELL NUMBERS OF START OF RESPECTIVE FILLS (NBF VALUES): IBFS(I)

I.7 GRID CELL NUMBERS OF END OF RESPECTIVE FILLS (NBF VALUES): IBFE(I)

I.8 ADDED BERM WIDTHS AFTER ADJUSTMENT TO EQUILIBRIUM CONDITIONS (NBF VALUES): YADD(I)

J----------------------------- BYPASSING --------------------------------J
J.1 ANY BYPASSING OPERATIONS DURING SIMULATION PERIOD? (NO=0, YES=1): IBP
0
J.2 COMMENT: IF NO BYPASSING OPERATIONS, CONTINUE TO K.
J.3 READ BYPASSING RATES FROM A FILE OR SPECIFY BELOW? (FILE=1, BELOW=2): IBPF
2
J.4 COMMENT: IF BYPASSING OPERATIONS ARE SPECIFIED BELOW, CONTINUE TO J.8
-- BYPASSING OPERATIONS SPECIFIED IN SEPARATE DATA FILE --
J.5 DATE OR TIME STEP WHEN BYPASS DATA FILE STARTS AND ENDS, RESPECTIVELY (FORMAT YYMMDD: 1 MAY 1992 = 920501): QQDATS QQDATE

J.6 CELL NOS. WHERE BYPASS FILE STARTS AND ENDS, RESPECTIVELY: IQQS, IQQE

J.7 COMMENT: END OF BYPASS DATA FILE SECTION. CONTINUE TO K.
-- BYPASSING OPERATIONS SPECIFIED IN THIS FILE --
J.8 NUMBER OF BYPASSING OPERATIONS DURING SIMULATION PERIOD: NBP
0
J.9 DATES OR TIME STEPS WHEN THE RESPECTIVE OPERATIONS START (DATE FORMAT YYMMDD: 1 MAY 1992 = 920501, NBP VALUES): BPDATS(I)

J.10 DATES OR TIME STEPS WHEN THE RESPECTIVE OPERATIONS END (DATE FORMAT YYMMDD: 1 MAY 1992 = 920501, NBP VALUES): BPDATE(I)

J.11 GRID CELL NUMBERS OF START OF RESPECTIVE OPERATIONS (NBP VALUES): IBPS(I)

J.12 GRID CELL NUMBERS OF END OF RESPECTIVE OPERATIONS (NBP VALUES): IBPE(I)

J.13 BYPASSING RATES AS TOTAL AVERAGE VOLUME PER HOUR (CY/HR OR M3/HR, ACCORDING TO UNITS GIVEN IN A.2) FOR RESPECTIVE OPERATIONS (NBP VALUES): QBP(I)

K------------------------------ COMMENTS --------------------------------K
* ALL COORDINATES MUST BE GIVEN IN THE "TOTAL" GRID SYSTEM
* ONE VALUE FOR EACH STRUCTURE, TIP ETC. ESPECIALLY IMPORTANT FOR COMBINED STRUCTURES, E.G., TWO DBW'S WHERE THE LOCATION WHERE THEY MEET HAS TO BE TREATED AS TWO TIPS.
* ANY GROIN CONNECTED TO A DETACHED BREAKWATER MUST BE REGARDED ASDIFFRACTING
* CONNECTED STRUCTURES MUST BE GIVEN THE SAME Y AND D VALUES WHERE THEY CONNECT
* IF DOING REAL CASES, THE WAVE.DAT FILE MUST CONTAIN FULL YEARS DATA
* DATA FOR START OF BEACH FILL IN SPACE AND TIME SHOULD BE GIVEN IN INCREASING/CHRONOLOGICAL ORDER. DATA FOR END OF BEACH FILL MUST CORRESPOND TO THESE VALUES, AND NOT NECESSARILY BE IN INCREASING ORDER.
* DON'T CHANGE THE LABELS OF THE LINES SINCE THEY ARE USED TO IDENTIFY THE LINES BY GENESIS.
* GENESIS95 GRAPHICAL USER INTERFACE FOR WINDOWS 95 CREATED BY PERON AT PERON SOFTWARE & HARDWARE (peron@pobox.org.sg). COPYRIGHT 1996
---------------------------------- END -----------------------------------

10.2. Appendix 2

Mathematical modelling of shoreline evolution

In this appendix the modelling program GENESIS will be described, explaining the theoretical formulation, numerical implementation and the accuracy of the model testing.

The reference to this appendix is Hanson & Kraus (1989), if nothing else is stated.

History of GENESIS

A previous version to GENESIS was developed during the Nearshore Environment Research Center project in Japan. In 1987 Hanson compiled the structure of GENESIS in a combined research project between the University of Lund and the Coastal Engineering Research Center (CERC), the US Army Engineer Waterways Experiment Station.

The first public version of the model was GENESIS version 2 and it was released in December 1989. A technical documentation was provided by Hanson and Kraus and is commonly known as the Technical Reference manual. Version 2.5 and the GENESIS system support programs, which automated many of the tasks that were done using the GENESIS model, were released in September 1991. An integrated interface for the GENESIS system support programs, the numerical models GENESIS and RCPWAVE (external wave model) and their model configuration data editors and graphic programs was released in August 1992, named Shoreline Modelling System (SMS). The current version of the model being used is number 3 (Gravens).

Theoretical formulation

GENESIS is a numerical one-line modelling system that simulates long-term shoreline change, which is created by spatial and temporal differences in the sand transport along the shore, at coastal engineering structures. GENESIS is an acronym that stands for GENEralized model for SImulating Shoreline change. The model is built to calculate the coastal sediment transport as efficient and accurate as is plausible even due to limitations in the data and in understanding of the sediment transport and how the shoreline changes. The central task of the model is to simulate the shorelines response to constructions situated on or near the shore.

This chapter explains the theory of shoreline response modelling and the mathematical structure of GENESIS. The modelling programme is applicable to a number of coastal engineering situations and is therefore both flexible and economical in its calculations.

Basic assumptions of shoreline change modelling

The GENESIS model is called the “shoreline change”, “shoreline response” or “one-line” model, the later is short for “one-contour line” model. This is because of the assumption that if the profile of the beach remains constant, any point on it can be used to give the location of the entire profile with respect to a baseline. The description of the change in the beach plan shape and volume can therefore be made by one contour line, which is defined by the observed shoreline. The alongshore transport of sand is presumed to take place between two well-defined limiting elevations along the beach profile. The limit towards the shore is located at the top of the active berm and the seaward limit is set where no considerable depth change occurs. Between these two limits there are a limitation in profile movement and this gives a boundary to a cross-sectional area from which changes in volume can be calculated, and thereby leading to understanding of the shoreline change.

There is a requirement to input prognostic expressions for the total longshore transport rate in the model. It is assumed that the trend of the movement of the shoreline is looked at in a long-term perspective, with the outcome that it is the waves (and not storms and deviating weather) that create longshore sand transport and the boundary conditions that are the major elements controlling the long-term beach change.

Main equations for shoreline change

The preservation of sand volume is the central equation when modelling shoreline change. In a right-handed Cartesian coordinate system the x-axis is defined following the coastline and the y-axis orients offshore, see Figure A:1. Thus, y denotes the position of the shoreline and x denotes the distance alongshore. The movement of a section of the coast towards the sea or the shore is assumed to progress without altering beach profile shape when a net amount of sediment enters or leaves the section during a time interval Δt. The change in shoreline position is Δy and the length of the shoreline segment is Δx.

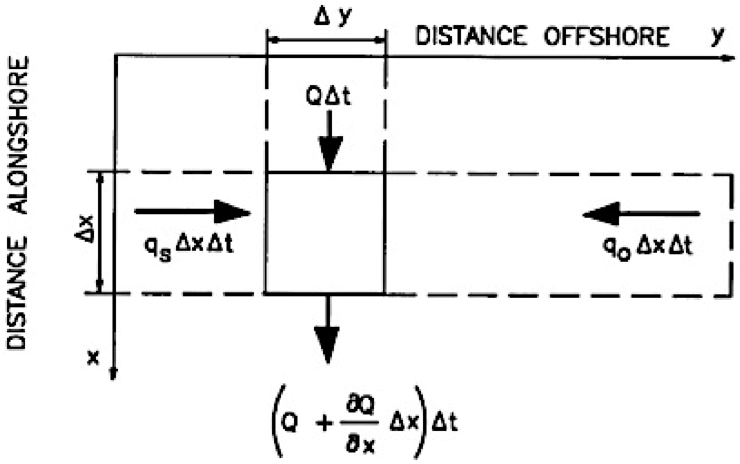

Figure A:1 Definition sketch for shoreline change calculations, plan view

The beach profile moves within a vertical area defined by the berm elevation D_B and the seaward limiting depth D_C, both measured from a vertical datum e.g. mean sea level (MSL) or mean lower low water (MLLW), see Figure A:2.

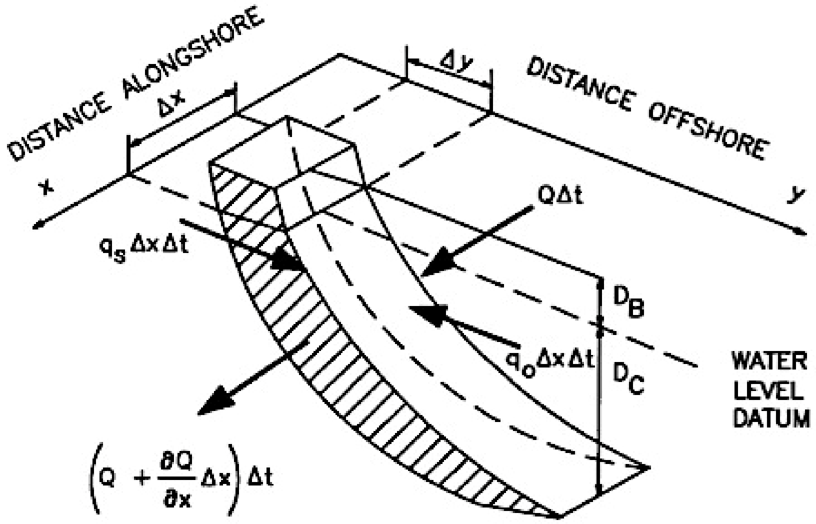

Figure A:1 Definition sketch for shoreline change calculations, cross-section view

The net amount of sand that enters or exits the section through any of its four sides defines the change of volume of the section

$$\Delta V = \Delta x \Delta y (D_B + D_C)$$

At two sides of the cell, through which the flow parallel to the shoreline passes, there can be a difference ΔQ in the longshore sand transport rate Q that leads to a change in net volume

$$\Delta Q \Delta t = -\left(\frac{\partial Q}{\partial x}\right) \Delta x \Delta t$$

From either the shoreward side, at the rate of q_s, or the offshore side, at the rate of q_o, there can be an addition or removal of volume of sand per unit width of the beach. There are no predictive formulas that is applicable on a general situation, the magnitudes usually vary with time and are a function of the distance to the beach. The total change q can come from a line source or a sink of sand and produce a volume change of

$$q \cdot \Delta x \Delta t$$

Adding up the contribution $\Delta Q \Delta t$ from the longshore sand transport with the source or sink of sand q and equating them to the volume change $\Delta \mathrm{V}$ gives

$$\Delta \mathrm{V} = \Delta x \Delta y (D_B + D_C) = -\left(\frac{\partial Q}{\partial x}\right) \Delta x \Delta t + q \cdot \Delta x \Delta t$$

With the limit $\Delta t \rightarrow 0$ and $\Delta x \rightarrow 0$ yields the equation for the rate of change of shoreline position

$$\frac{\partial \mathrm{y}}{\partial t} + \frac{1}{(D_B + D_C)} \cdot \left(\frac{\partial \mathrm{Q}}{\partial x} - q\right) = 0 \qquad (1)$$

To solve equation 1 the position of the initial shoreline, the boundary conditions and the values for Q, q, D_B and D_C must be entered into the model.

Longshore sand transport

The empirical formula that GENESIS uses to predict the longshore sand transport rate is

$$Q = \left(H^2 C_g\right)_b \left(a_1 \sin 2\theta_{bs} - a_2 \cos \theta_{bs} \frac{\partial H}{\partial x}\right)_b \qquad (2)$$

where

H = wave height
C_g = wave group speed given by linear wave theory
b = subscript denoting wave breaking condition
θ_{bs} = angle of breaking waves to the local shoreline (see Figure A:3)

The non-dimensional parameters a_1 and a_2 are given by

$$a_1 = \frac{K_1}{16 \cdot (\rho_s / \rho - 1)(1 - p) \cdot 1.416^{5/2}}$$

and

$$a_2 = \frac{K_2}{8\cdot(\rho_s/\rho-1)(1-p)\cdot\tan\beta\cdot 1.416^{7/2}}$$

where

K_1, K_2 = empirical coefficient, treated as a calibration parameter
θ_s = density of sand (taken to be $2.65 \cdot 10^3\ kg/m^3$for quartz sand)
θ= density of water ($1.03 \cdot 10^3\ kg/m^3$for seawater)
p = porosity of sand on the bed (taken to be 0.4)
$\tan\beta$ = average bottom slope from the shoreline to the depth of active longshore sand transport

GENESIS requires the root-mean-square wave height (H_{rms}) and the factor 1.416 convert the significant wave height that is used as the input wave height.

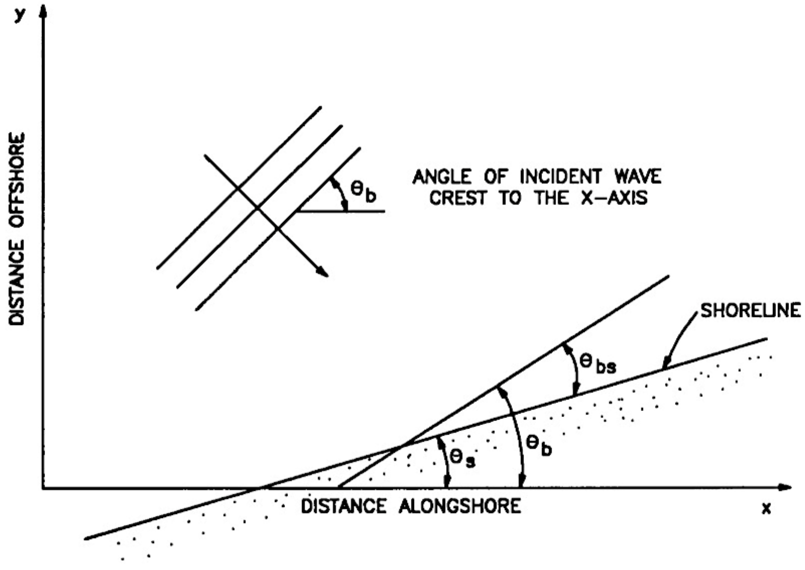

Figure A:2 Definition of breaking wave angles

In equation 2 the first term equals the CERC formula that estimates the total longshore sediment transport rate created by obliquely arriving breaking waves. The value of K_1 has been derived from different sand tracer experiments and a typical value lies within the range of 0.58 to 0.77. For a sandy beach the value of K_1 usually have a value between 0.1 and 1.0. The second term describes the effect of the longshore gradient in breaking wave height $\partial H_b/\partial x$, which also creates longshore sediment transport but commonly it has a minor impact compared to the sand transport created by the first term. Though, near constructions the second term has a larger effect on the modelling result, because diffraction creates a significant change in breaking wave height over an extensive length of the beach. The value of K_2 is normally set to 0.5-1.0 times the value of K_1. Both K_1 and K_2 are used as calibration parameters and are often called transport parameters as K_1 controls both the time scale of the model and the quantity of the longshore sand transport rate. Through a reproduction of the known shoreline change and the longshore sediment transport magnitude and direction, the values of the calibration parameters can be set.

Empirical parameters

The profile width over which the longshore transport occurs is set to the width of the surf zone, since the large part of the movement of sand along the shore happens in the surf zone. The width of the surf zone depends on the breaking wave height of the incoming waves. The depth of active longshore transport, D_{LT}, has a direct relation to the width of the surf zone and is defined as the breaking depth of the highest ten per cent of all waves H_{10} at the updrift side of the construction. The factor 1.26 converts the significant wave height $H_{1/3}$ to H_{10}.

$$D_{LT} = \frac{1.26}{\gamma}(H_{1/3})_b$$

where

$(H_{1/3})_b$ = significant wave height at breaking
γ = breaker index, ratio of wave height to water depth at breaking

To calculate the average beach slope $\tan\beta$ the maximum depth of longshore transport D_{LTo} is used and the depth is calculated at every time step from the deepwater wave data.

$$D_{LTo} = (2.3 - 10.9 \cdot H_o)\frac{H_o}{L_o} \qquad (3)$$

where

H_o/L_o = wave steepness in deep water
H_o = significant wave height in deep water
L_o = deepwater wavelength, $L_o = gT^2/2\pi$

There is a seasonal variation of the wave characteristics and it gives that the depth D_{LTo} also changes over the year as the average profile shape and beach slope change. To calculate the shoreline change there is no need to define the bottom profile shape, the assumption that the profile moves parallel to itself is made. The shape of the profile is needed though to calculate the average nearshore bottom slope and to be able to define the position of breaking waves alongshore. An average shape profile for a beach can be described by

$$D = Ay^{2/3}$$

where

D = water depth
A = empirical scale parameter

It has been shown that A is related to the grain size of the beach and GENESIS uses a design curve to give A a value. To receive the most accurate shape of the profile the effective grain size should be used and if sufficient data is not available use the median grain size of the surf zone. The average slope is computed by

$$\tan\beta = \left(\frac{A^3}{D_{LTo}}\right)^{1/2}$$

Wave calculation

GENESIS uses wave data measured by a wave gage or gained through hindcast calculations. The wave input data is used with a fixed interval, usually in a time span between 6 and 24 hours. There are two key submodels in GENESIS; the first one calculates the longshore sand transport rate and shoreline change (as discussed earlier) and the second one is called the internal wave transformation model, which will be looked into in this chapter. The offshore wave data has to be recomputed to the breaking wave height and the angles of the incoming waves are calculated with respect to the normal of the shoreline's baseline. The internal transformation model differs from an external ditto due to the fact that the internal can be used when the ocean bottom contours are close to straight and parallel. An external wave transformation model performs the calculations over the real, varying bathymetry, starting at the offshore reference depth, see Figure A:4. When choosing which model to use the accessibility and dependability of the wave data and how complex the bathymetry is, are the parameters to evaluate.

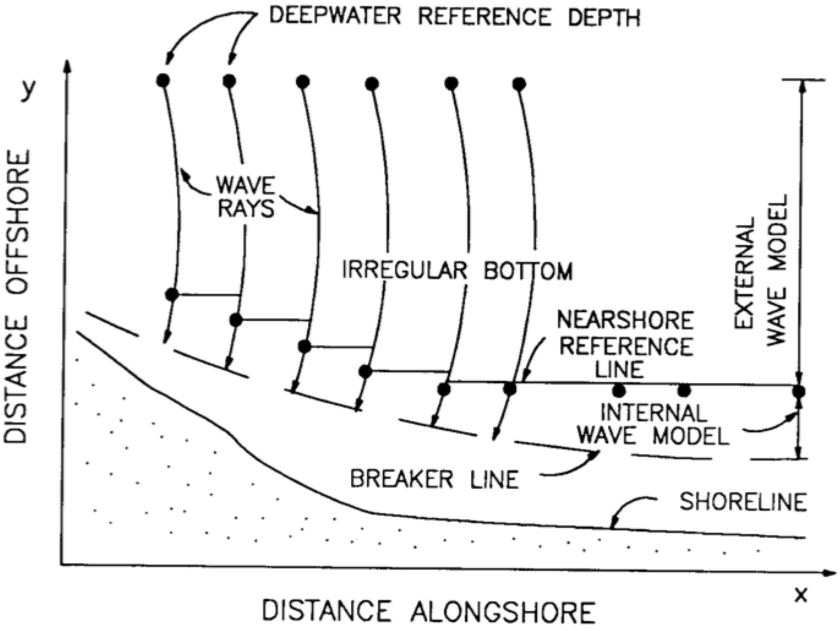

Figure A:3 Function of external wave transformation model

For the internal model (see Figure A:5) the height of the breaking waves H_b, the water depth at breaking D_b and the angle of the wave rays θ_b (see Figure A:3) are calculated at grid points located along the coast, with the start at the reference depth of the offshore wave input. The first calculations on the wave transformation are made with the wave diffraction from coastal structures neglected and the result is later on modified through taking diffracted waves into account.

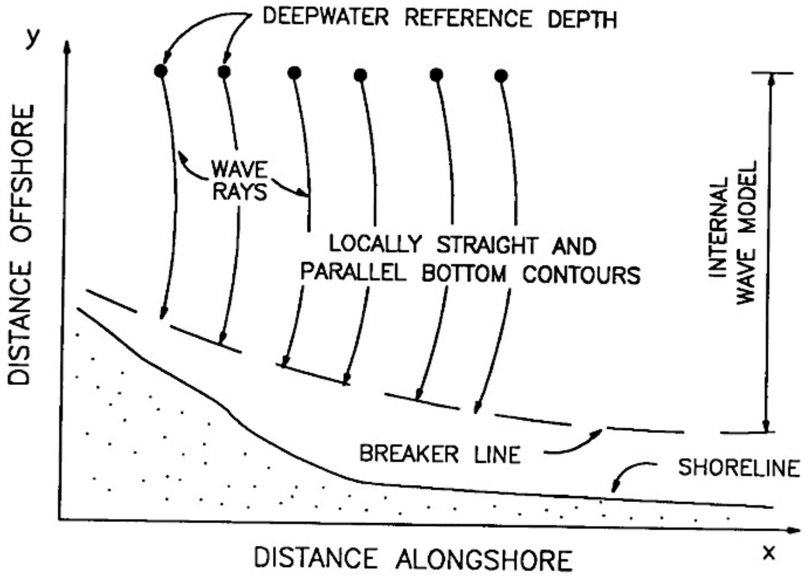

Figure A:4 Function of internal wave transformation model

The incoming waves will be affected by refraction and shoaling and the height of the breaking waves are calculated with

$$H_b = K_R K_S H_{ref} \tag{4}$$

where

H_b = breaking wave height at an arbitrary point alongshore
K_R = refraction coefficient
K_S = shoaling coefficient
H_{ref} = wave height at the offshore reference depth or the nearshore reference line depending on which wave model is used

The refraction coefficient K_R is a function of the initial angle θ_1 of the wave ray and the angle θ_b of the breaking wave at the position P_b of the breaking depth. The shoaling coefficient K_S is a function of the wave group speeds C_g at a position P_1 offshore respectively at P_b where the waves break.

The breaking wave depth D_b is a function of the breaking wave height H_b and the breaker index γ

$$D_b = \frac{H_b}{\gamma} \tag{5}$$

Snell’s law is used to calculate the wave angle at breaking θ_b

$$\frac{\sin\theta_b}{L_b} = \frac{\sin\theta_1}{L_1} \qquad (6)$$

L_b is the wavelength at breaking and L_1 and θ_1 is the wavelength respectively the wave angel at an offshore point.

The parameters needed from the internal wave transformation model are gained at intervals along the shore by iterative solution of equations 4, 5 and 6. If there are no constructions in the area of modelling the wave characteristics obtained from the wave transformation model can be used directly as input to the sediment transport calculations. If a structure, e.g. detached breakwater, jetty or groin, extend out of the surf zone and intercept waves before breaking, the creating a distortion of the wave field will take place and has a substantial impact on the shoreline response in the shadow of the structure. The breaking wave height in the lee of the structure, which is transformed by refraction, diffraction and shoaling, is calculated by

$$H_b = K_D(\theta_D, D_b)H_b' \qquad (7)$$

where

K_D = diffraction coefficient, a function of θ_D and D_b
θ_D = angle between incident wave ray at P_1 and straight line between P_1 and P_2, if P_2 is in the shadow region (see Figure 6:6)
H_b' = breaking wave height at the same cell without diffraction

H_b, D_b and θ_b are obtained at intervals along the beach by iterative solution of equation 7, 5 and 6.

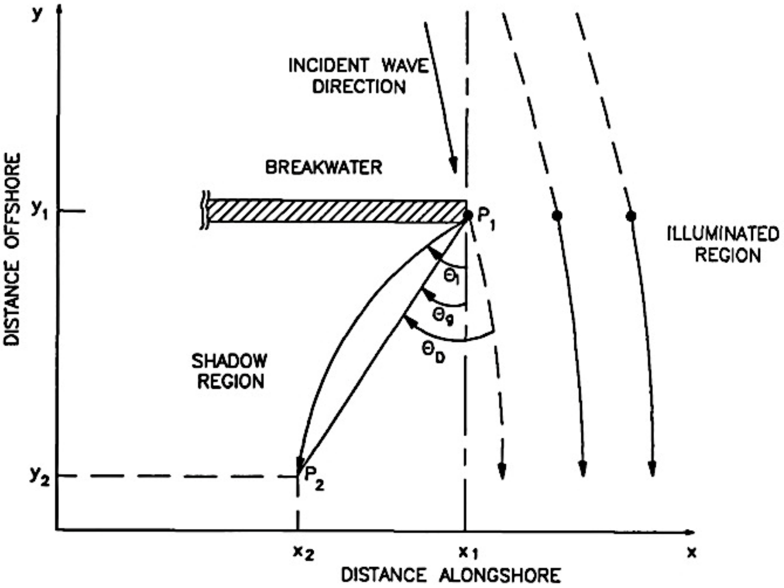

Figure A:5 Definition sketch for angle θ_D

Grid system

Computed quantities along the coastline are discretized (transferred from continuous models and equations into discrete equivalents) on a staggered grid, with the shoreline positions y_i defined at the midpoint of the grid cells and the transport rates Q_i at the cell walls, see Figure A:7. Grid cell 1 is defined by the left boundary and at cell N is the right boundary, which gives N values of the position of the shoreline and the position of the initial beach must be defined at N points. There are N+1 cell walls that give N+1 values of the longshore sand transport rate. At the boundaries, Q_1 and Q_{N+1}, the transport rate must be given through a boundary condition (discussed in chapter 6.3.3). The choice of size of the grid spacing and the time step reflects on how accurate the numerical solution will be and how long time it will take to run the model.

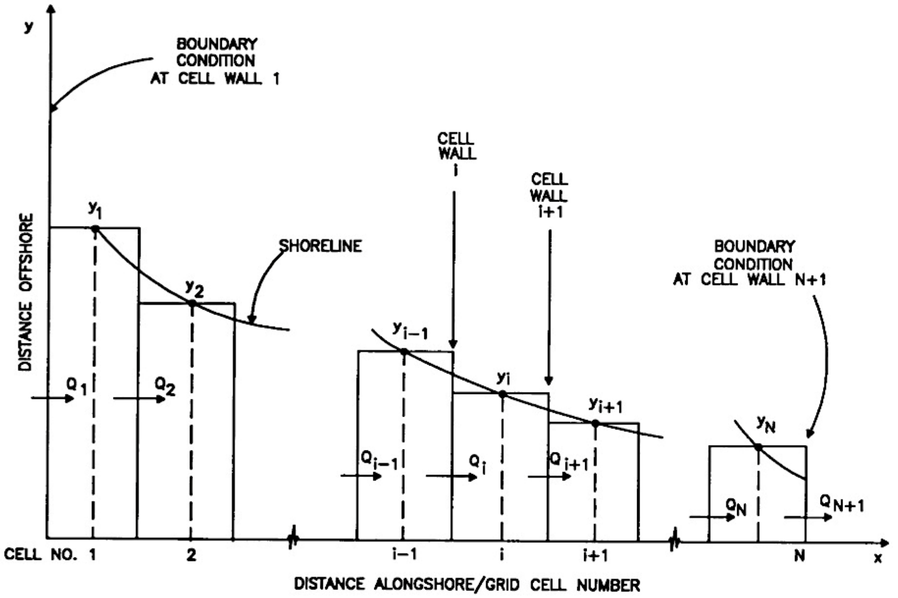

Figure A:6 Finite difference staggered grid

Numerical solution scheme

The shoreline response to wave action can be modelled when all the information needed for the shoreline change equation (equation 1), the longshore sand transport rate (equation 2) and the wave breaking criterion (equation 5) are gathered. GENESIS uses an implicit solution scheme to solve equation 1, a solving method that finds a solution to an equation by involving both the current state of the system as well as the later, apart from an explicit solution scheme that uses the system state at current time to calculate the state of the system at a later time. The implicit solution scheme is much more stable but with the disadvantages of a much more complex modelling setup.

The derivative $\partial Q/\partial x$ at each grid point is expressed as an equally weighted average between the present time step and the next time step

$$\frac{\partial Q_i}{\partial x} = \frac{1}{2}\left(\frac{Q'_{i+1} - Q'_i}{\Delta x} + \frac{Q_{i+1} - Q_i}{\Delta x}\right) \qquad (8)$$

The prime denotes a quantity at the new time level and the known quantities at present time are unprimed. Some primed quantities are known in the next time step, such as q' and D'_B whereas the quantities y' and Q' are the ones looked for in the modelling process.

Insertion of equation 8 into equation 1 and linearization of the wave angles in equation 2 in terms of $\partial y/\partial x$ results in two systems of coupled equations for the unknowns y'_i and Q'_i

$$y_i' = B'(Q_i' - Q_{i+1}') + yc_i \tag{9}$$

and

$$Q_i' = E_i(y_{i+1}' - y_i') + F_i \tag{10}$$

where

$B' = \Delta t / (2(D_B + D_C') \cdot \Delta x)$
yc_i = function of known quantities, including q_i' and q_i
E_i = function of the wave height, wave angle and other known quantities
F_i = function similar to E_i

Numerical implementation

The shoreline change model

A model can have a longshore reach of 1 to 100 km and a simulation can be run at a time span from 1 to 100 months. Settings that have a systematic trend in the long-term variation of the position of the shoreline are the most applicable on the model. The cross-shore sediment transport that also creates a shoreline change is not available for modelling with GENESIS, but the effect is assumed to average out over time.

The numerical model is a generalization of analytical shoreline change models and is a one-linear model, which performs a time-dependent sediment budget analysis. The assumption of constancy of the beach profile shape along the shore gives that the landward and seaward movement of any contour could be used in the modelling as beach position change. The datum line (shoreline position) is a known parameter due to measurements and this gives that the correspondent contour line is taken to be the shoreline. The ends of the model grid along the shore are represented by boundary conditions and together with the longshore sand transport these are the cause of beach change in the shoreline change model. Beach fills and river discharges as well as inlets and sand mining, also known as sources or sinks of sediment, can be taken into account in the model.

Creating a conceptual model

Background information is collected from physical data and gives general insight to the coastal processes in the area and the geography of the region. The data is also required to calibrate, verify and make predictions. When creating the conceptual model the first thing to set up is the shoreline coordinate system that follows the trend of the local shoreline and the longshore x-axis is drawn parallel to the beach trend. The y-axis is normal to the shoreline and creates a coordinate system as shown in Figure A:8. The spacing of the alongshore grid is determined from the data quality, how large the modelled area is and the desire in detail.

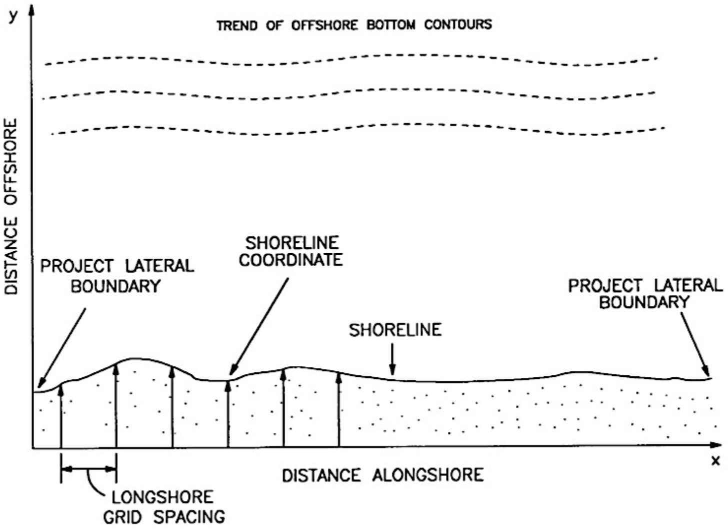

Figure A:7 Model coordinate system

The input data needed for the model are the position of the shoreline, wave data, alignments of structures, other coastal measures in the area, beach profiles and boundary conditions. To be able to do an interpretation of the model output, regarding sediment transport processes and beach change, information on the regional transport of sediments, the regional geology, water levels regarding the tidal and other datums, extreme events and other site specific parameters that will affect the modelling are needed.

Data on the position of the shoreline can for example be acquired from shoreline surveys, beach profile surveys, photographs over the area, maps and nautical charts. The shoreline position refers to the zero-depth contour in relation to a certain datum, for example the mean sea level, and the same datum should be used for the bathymetry data. Measured wave data is obtained from a wave gage but to have wave data that is sufficient for running the model is rare and if measured values are not available different methods are available for calculating estimated values. Wave hindcasting or calculation from wind data obtained e.g. from a nearby meteorological station, buoy or airport are two ways to obtain useful wave data.

If there are any coastal structures or other engineering measures, such as beach fills, in the area they must be positioned in the model grid with respect to both time and location. GENESIS can simulate the change in structures and measures over time, therefore data regarding locations, configurations, times and volumes (in the case of beach fill, dredging and sand mining) need to be gathered and estimations of parameters such as permeability factors for groins must be made. The bathymetry of the area could be derived through profile surveys or read from bathymetry charts, if there are any available, and the data obtained from the two methods should also be compared. The data used has to be from the same time period, especially if an inlet is located in the modelling area since then ebb shoals can change a lot. The average height of the berm, the depth of closure and average profile slope are data needed to run the model in GENESIS.

Lateral boundary conditions

Boundary conditions must be specified at both ends of the numerical grid, at the ends of the modelling area. The rate of sediment transport, in or out of the modelled area, are set at the boundaries and can have a fundamental effect on the change of the shoreline.

GENESIS calculates the net and gross longshore sand transport rates that can be compared with empirically determined rates. The sand transport rates have a direct correlation to the boundary conditions and a comparison helps to define more accurate boundary condition parameters. There are two types of fixed boundary conditions that can be used in GENESIS: a gated boundary condition or a pinned-beach ditto. A gated boundary condition refers to that the boundary has been specified with a groin, jetty, or some similar construction. A pinned-beach boundary condition states that the boundary has shown a long-term trend of stability and is situated far away from any coastal structures that can have impact on erosion or accretion of the beach.

Calibration and verification of the model

The calibration of a model refers to the process of reproducing the measured positions of the shoreline over time with a created model. The procedure of applying the calibrated model to recreate changes measured over a different time interval is called verification. These two steps show that the model calculations run correctly regardless of the calibration interval, but do not guarantee that the model always can be run because conditions in the studied area can easily change.

Input files

There are six different types of data input files that can be used in GENESIS and three types of output files are created when running the model. The input files are called START, SHORL, WAVES, SHORM, SEAWL and DEPTH, and the first four files must be used, whereas SEAWL and DEPTH is optional. The output files that GENESIS creates are called SETUP, OUTPT and SHORC.

The START file contains the instructions that controls the model and contains information regarding the creating of the model grid, time interval for the model, values of K_1 and K_2, wave manipulation, information regarding the wave data, the beach and possible coastal structures and beach fill.

SHORL contains the position of the initial shoreline that is used by GENESIS at the beginning of the modelling. SHORM holds the coordinates of the measured shoreline, to which the calculated coastline position is calibrated against. Both

SHORM and SHORL need to contain the same amount of coordinates as there are number of grid cells defined in the START file.

The WAVES input file holds the wave data that controls the longshore sediment transport rate. The wave data that is needed are the significant wave height (metres), wave angle (degrees) and wave period (seconds). The amount of wave data does not have to correspond with the chosen time period, if the end of the WAVES file is reached the file will be read again from beginning.

The input file SEAWL contains the positions of one or more seawalls located within the modelling area. The DEPTH file is needed if an external wave refraction model has been used to provide wave data.

The output files contains different data obtained from running the model. In SETUP the basic information and instructions entered in the START file is found along with error messages and warnings, if there are any. OUTPT contains the major output and results from the calculations; calculated shoreline positions, volume of sand transported alongshore and the sand transport rate and breaking wave height. In SHORC the calculated shoreline at the last time step in the simulation is found and this file can be copied to SHORL to get the initial shoreline for the next stage of the simulation. GENESIS also calculates a calibration/verification error as the average of the absolute difference between the positions of the calculated shoreline (SHORC) and the measured shoreline (SHORM).

Model testing for accuracy and sensitivity

The testing of a models’ sensitivity is done through examining changes in the output when deliberately have done alterations of the input data. If small changes in the input data results in large changes in the output, a conclusion regarding whether the quality of the verification is enough for a practical application. No model will provide a correct prediction of the change of the shoreline, but with a range of runs of the model and a possibility judgement the most probable result can be selected. GENESIS is not usually sensitive to small changes in parameter values, but a sensitivity test should be performed nevertheless.

When checking the reliability of the output from a model run the overall trend of the position of the shoreline should be checked besides the dominant features. The net and gross longshore sediment transport should correlate with independent estimations. Through verifications, sensitivity analysis and modelling of alternative plans knowledge have been gained that helps in finding errors and misleading results. Plots of calculated results should be compared with mathematical methods, such as the calculated calibration/verification error, to find different types of errors.